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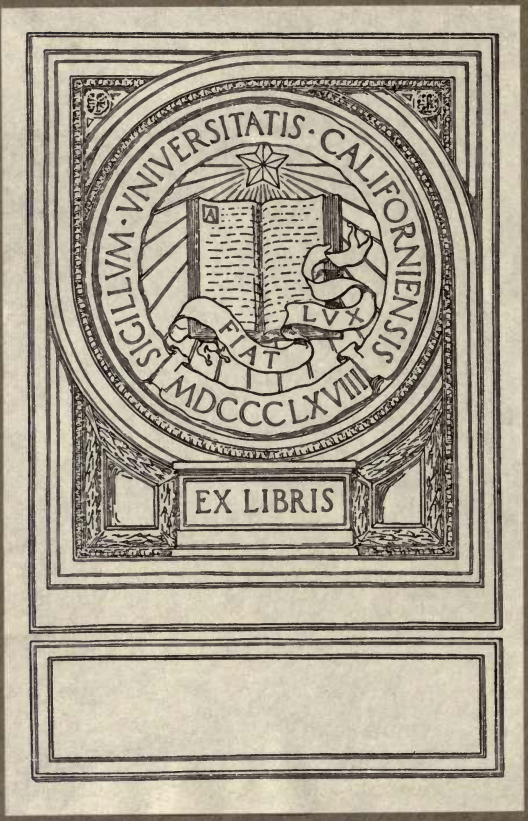
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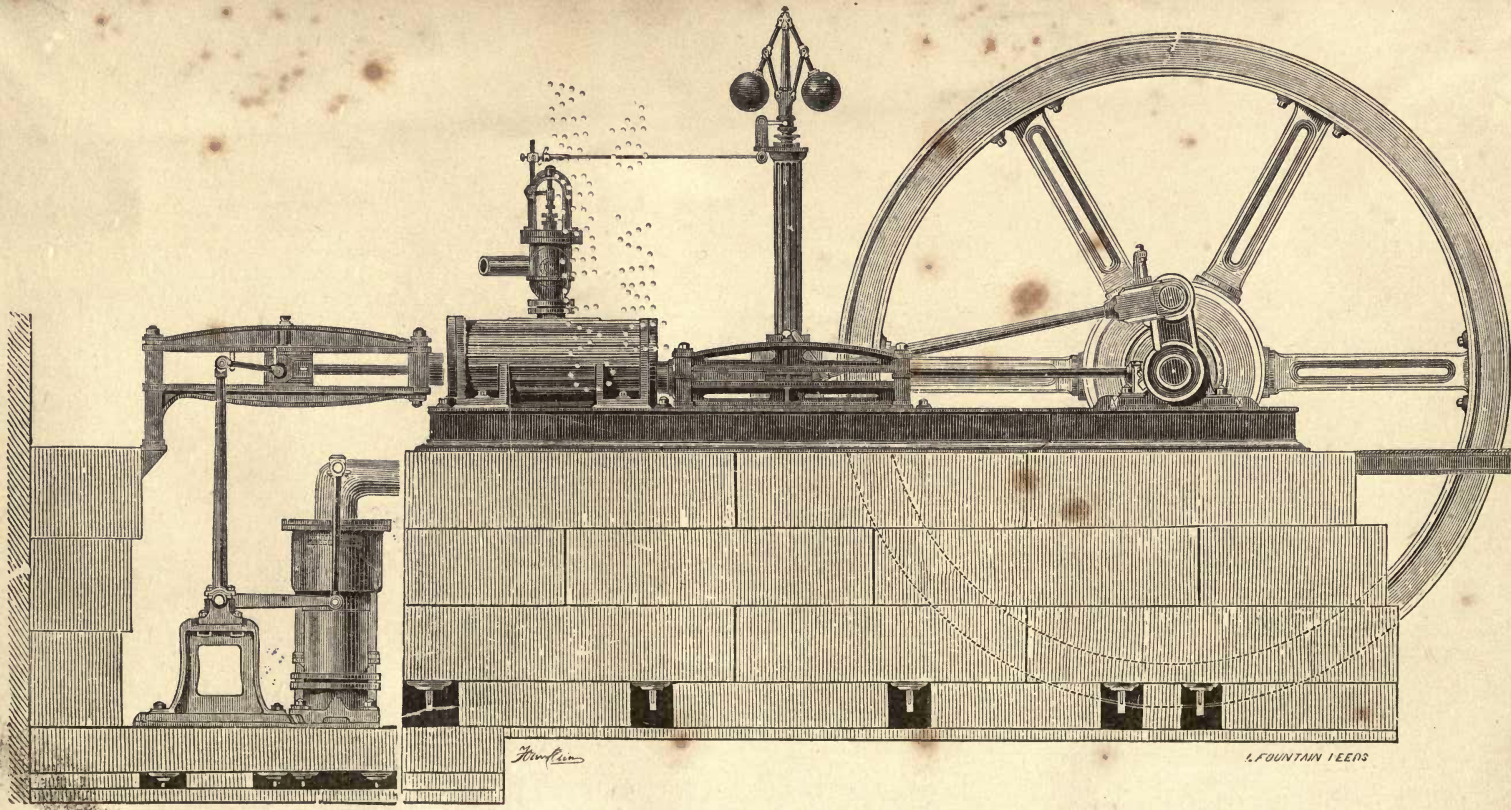

DIRECT-ACTING HORIZONTAL ENGINE, TWENTY NOMINAL HORSE POWER.

Thomas Davis
Age. 1866.

THE WORKING ENGINEER'S PRACTICAL GUIDE

TO THE

MANAGEMENT OF THE STEAM ENGINE AND BOILER:

WITH RULES AND INSTRUCTIONS FOR

VALVE SETTING:

SO AS TO SECURE A FULL DEVELOPMENT OF THE MOTIVE POWER.

ILLUSTRATED BY DIAGRAMS AND ENGRAVINGS.

Brass

BY JOSEPH HOPKINSON,

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PREFACE.

With confidence the Author submits the present work, "The Working Engineer's Practical Guide," to the judgment of those whose duty it is to superintend the working of the Steam Engine and Boiler, in their many and varied forms and applications. The many encomiums the Author has received from parties who have benefited from following the instructions and advice contained in his larger work, "The Working of the Steam Engine Explained by the Use of the Indicator,"—(four large Editions of which have been published, and rapidly disposed of,)—and the very general desire he has heard expressed that portions of the matter composing that work should be published in a form and at a price more accessible to the working Engineer, has induced him to prepare the work now presented, in the confident belief that it will be found to be of practical advantage to those for whose information and use it has been designed.

The aim of the Author, in all he has published, has been, by means of homely language, accompanied with familiar and practical illustration, to instruct those who are entrusted with the care and management of Steam Engines, so that they may ascertain with certainty whether they are deriving the greatest amount of practical advantage from the several quantities of impulsive power they may generate and apply. Interspersed with these instructions he has given hints and examples, intended to show how practical improvements in the working of most Steam Engines may be effected at little cost, to the great saving of fuel, and the steady application of the motive power—all these being points of manifest importance to the proprietors of Steam Engines, and of advantage to the practical Engineer. The conclusions recorded in this work have resulted from observation and study, not in the closet, but in company with the Steam Engine, in its various stages and alterations: and although the mere theorist, or the scientific literary writer, may object to the plain and simple manner in which the different topics descanted on are treated, the Author is assured, from the difficulties which in the early period of his own experience he himself had to contend with and overcome, that his plan of procedure is the best that he could possibly have adopted for the accomplishment of his main object in undertaking the work—the instruction of the practical *working* Engineer.

The chapters of the present work, on the management of the Boiler and Engine, will, the Author flatters himself, be found to contain instructions and

hints, calculated—if acted on and carried out—to be of great advantage to working Engineers, as well as to the proprietors of Steam Engines, by enabling the former to pursue their avocations so as to produce something like certainty of results, and to know, in a great measure, the cause of any derangement in the working of either the Boiler or Engine that may occur.

The section of the work devoted to the question of the Expansion of Steam, with the examples adduced, shows how this is to be effected in the most available manner with the best practical results. The Author knows of nothing else hitherto published which imparts the information on this important subject he has endeavoured to convey. Yet this is one of the real questions of the the day —the main direction in which further improvements of the Steam Engine are to be effected. Economy in the working of the Steam Engine is known to be in the application of *high pressures*. The higher—within the limits of safety—we can get, the more economical. To obtain the whole benefit of high steam, we must apply the principles of Expansion, beginning with the highest pressure of steam we have, and parting with it at the lowest possible pressure. How this principle is to be applied with practical advantage, the Author has here endeavoured to indicate.

The Tables appended to the work will also, it is believed, be found to be of service to the practical Engineer, aiding him in his calculations for various matters connected with the Steam Engine and its working. In those Tables, and indeed, throughout the work, decimals have been, to a great extent, dispensed with, and also fractional parts, with the exception of those expressed by the common signs $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$,—the calculations when so reduced and expressed, being near enough for all practical purposes, and more intelligible to a large portion of the class for whom the work is designed. In fact, throughout the treatise, the aim of the Author has been to express himself in simple phraseology; and though his production may not possess the charm of literary embellishment, he trusts that it may be found to possess at least the merit of perspicuity in the treatment of a dry subject, and to be of practical utility. In short, he trusts that it will be found to be what he has endeavoured to make it, a "PRACTICAL GUIDE TO THE WORKING ENGINEER."

BRITANNIA WORKS,
Huddersfield, January, 1866.

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THE WORKING ENGINEER'S PRACTICAL GUIDE.

CHAPTER I.

ON THE MANAGEMENT OF THE BOILER AND STEAM ENGINE.

THE duties of an Engineer, entrusted with the managenent of a Steam Engine and Boiler, are of more importance than at first sight would appear. He ought to be attentive, and conversant with all the details of the constructions placed in his charge, otherwise he will be liable to make mistakes, and may unwittingly cause much damage.

Boilers require careful and constant attention : but under the control of judicious managers, with proper fittings, they are perfectly safe, when properly constructed. But when their construction and management fall into the hands of incapacity and ignorance, or where reckless folly and hardihood have their full fling, death and destruction almost inevitably follow.

As this work is intended to be of practical service to the Working Engineer, we shall, in homely style, and with familiar illustrations and examples, endeavour to make plain and understandable the several duties connected with his avocation. And first, of

THE GENERAL MANAGEMENT OF THE BOILER.

The Boiler and Furnace require the especial attention of the Engineer, these being the places where the power he has to apply and regulate is first generated, and from which the most dangerous consequences may arise, either from neglect or ignorance. The following short rules for good management ought to be deeply engraven on the memory of every one entrusted with the care of Steam Engine Boilers, viz :—

I.—All dirt and lumber ought to be kept from the top of the Boiler, and from every part of the Boiler-house, and no person admitted into the latter, except on business.

II.—It should be ascertained that the Boiler is properly stayed, where stays are necessary, particularly if fixed with angle iron ; and the cotters

(if any) kept up, and repaired as they are worn down ; and it should also be seen that all fixings attached to the Boiler are well riveted on, and good joints made with proper cement, free from injurious compounds detrimental to the metal of the Boiler. All leakages ought to be prevented, or stopped as soon as they are discovered, or they will soon destroy the Boiler. The flues and the surfaces exposed to heat should be kept clean. Soot and dirt are non-conductors, and cause a loss of fuel, besides decreasing the heat-conducting power of the Boiler.

III.—See that the feed-valve is in good working order ; see also that the float (if any) and glass-gauge are well attended to. If a self-regulating feeding apparatus is used, it should be closely watched, and on no account be implicitly trusted. Self-feeders to Boilers are liable to get out of order, from friction in stuffing-boxes from dirt, and from other similar causes. Ascertain that the pipes and taps of the gauge are not made up with dirt or scale. If gauge taps alone are used, do not rely upon them to test the height of the water in the Boiler. If the water be below the tap, the moment the latter is opened to test the height, the water in the Boiler primes, and rushes to the tap, and shows water when the Boiler is actually short—particularly where great pressure is used. Gauge taps have been the cause of many Boiler explosions, from having deceived the attendant. Where a float is used, see that the float-wire is not strained, or worn to a shoulder, but kept free in the packing ; and when worn smaller at the foot where the wire passes through the Boiler, see that it be renewed with a small wire—the smaller the better. Where steam is at a pressure above 10lbs to the square inch, the common float is of little use. In most cases, with high steam they are positively dangerous, and should not be trusted. Stop-valves, or other spindle-valves, should be constructed so that the thread on the spindle is *outside*, and may be seen at any time. This may be effected by means of a bridge-casting attached to the part through which the spindle-thread passes.

IV.—Be provided with means to prevent the steam getting to a greater pressure than fixed upon. Should the water from any cause become deficient, the safety-valve should let off the steam and stop the working, independent of any control, until water is again supplied in the required quantity : thus saving the Boiler from explosion. Often ascertain that the safety-valve is properly adjusted. Be particular that the spindle or guides (if any) have sufficient room to work, and also to prevent the parts adhering. In no case have a stuffing-box or spring to a safety-valve. Safety-valves, as commonly made and understood, are valves simply for the letting off of steam under certain calculated circumstances of pressure. Thus constructed, they are, in fact, only

steam-valves, and not safety-valves. A properly constructed safety-valve will not only liberate the steam when the pressure is too high from over-firing, but also when the water in the Boiler from any cause becomes too low for safe working. A proper safety-valve is also weighted in such a manner that when set at the pressure beyond which it is determined the steam shall not rise, that weight cannot be changed or tampered with whilst the Boiler is at work.

V.—Let the length of the safety-valve lever be as short as possible, to prevent the extreme pressure you are working at from being increased with the same weight. When the lever of a commonly constructed safety-valve is too long, the valve is easily tampered with. Indeed, the working pressure may, under such circumstances, be easily increased to or beyond the point of danger, by the weight being *accidentally* removed on the long lever. Let the joints of the fulcrum of the lever be of brass or some other metal that will not corrode, or cause the parts to oxydize and become fast. The fittings on the Boiler should be taken to pieces at least once a year, cleaned, refitted, and adjusted. This will prevent the parts becoming magnetised, and adhering to each other.

VI.—Whenever from any cause, the Boiler-plates become over-heated, *open the damper and furnace-doors to the full*, that the cold air may cool the Boiler. Closing the damper *increases* the heat in the flues, and by that means the danger is increased. Lead plugs or fusible metal inserted in the flues, do not melt at the temperature required, after being in use a short time; therefore place no reliance upon such contrivances. They only tend to lull the proprietor of the Steam Engine and the Engineer into a fancied security. Above all, do not admit water into the Boiler or relieve the pressure *suddenly*: as either will cause a violent agitation or foaming of the water—and this, washing over the heated plates, will generate more steam than the safety-valve can discharge—creating most imminent danger of an explosion. Under extreme circumstances of this nature, the water sent into the Boiler, or that brought into contact with the highly heated surface, will flash into high steam, just as if a quantity of gunpowder had been ignited within the Boiler, tearing everything asunder. The starting of the Engine is quite sufficient to produce a violent agitation of the water, by the pressure being relieved when the Boiler is overcharged with heat, and disastrous consequences may be the result. Above all, do not depend on open column-pipes inserted in the Boiler, as a means of safety from explosions; for though they will relieve at times from over-pressure—to the great danger in such cases of running the Boiler empty—they are positively dangerous from another cause. It has been ascertained, by experiment, that though the water in the Boiler may be reduced so low as to lay some of the plates

bare to the action of the fire, the water from the pipe will not descend below a certain point, but will hang from the bottom of the pipe in the form of a cone—a striking illustration of what is known as the cohesion of adhesion. Should this cone, from any cause, agitation or otherwise, become detached from the end of the pipe, and be dispersed over the heated plates, the consequences above pointed out are almost inevitable. In fact, these open column-pipes are no safeguard whatever against a Boiler becoming low in water, or, indeed, practically empty. Where a proper safety-valve has been applied, these open stand-pipes, fusible plugs, and also water-gauging taps are wholly unnecessary—as, with the former appliance it is impossible for the Boiler to become short of water and have pressure within it at the same time : the prevention of danger from this cause being, under the circumstances spoken of, sure and certain.

VII.—See that the dirt in the Boiler is well blown out. Some descriptions of water will require the Boiler cleansing every three hours, others not so often, according to the quality of the water. If this point be attended to, the Boiler will wear much longer, and seldom require opening; the consumption of fuel will also be much less. In Marine Boilers, the blowing out at stated intervals from the surface and the bottom, prevents the deposition of salt and lime, and is the only thing required to keep the Boilers clean.

VIII.—Have the feed water for the Boiler as hot as possible, and sent into the Boiler *near the surface* of the water inside. The cold water will descend; but before arriving at the bottom it will have become heated, thus tending to keep the Boiler at an even temperature. If the water injected be low in temperature, it should be well distributed in the mass of water already in the Boiler, and not allowed to impinge on any portion of the metal of the Boiler—or that portion of the Boiler where the cold water thus comes into contact will be liable to crack and rend, from the continual action of contraction and expansion which such an arrangement inevitably causes. When the water is sent into the Boiler near the bottom, it does not rise till it has become heated; and this mode of feeding therefore tends to keep the Boiler bottom cooler than the other portions—an evil which ought to be avoided. The Cornish, Double Fire-box, and Tubular Boilers are more subject to this evil of unequal expansion and contraction than most others. The Engineer should therefore have the feed-pipes raised in the Boiler, when they are inserted in or near the bottom, otherwise the Boiler may break in the centre, and cause much loss or damage by the parts of the Boiler separating. With round Boilers, with the fire under the bottom, and particularly where they are hard-fired, some mode should be devised to cause a continual circulation

of the water near to the bottom of the Boiler: otherwise the steam generated at that place will partially displace the water, and thus allow the plates to become overheated and weakened.

IX.—When there are two or more Boilers, with feed-pipes connected together, without a self-acting stop-valve between each, shut off the feed-valve to each Boiler during the night, or whenever it is not working; the water being liable otherwise to empty itself from one Boiler into another—as the pressure in the Boilers varies,—leaving one of the Boilers nearly empty; more particularly where there are Boilers working at different pressures. A self-acting stop-valve is in the last case absolutely necessary. But where Hopkinson's Patent Compound Safety Valve is on the Boiler, this will be prevented. Should the water lower, the valve will let off the steam, and the water will then be equalised, thus being what its name imports—a Safety-Valve under all circumstances.

X.—Where junction steam-valves are used, or a valve placed between the Boilers and the main steam-pipe, see that the valve-spindle is one without a weight or screw, and take every precaution to prevent the valve from being weighted down when the steam is up. Sometimes the safety-valve is on the steam-pipe; in that case junction-valves are dangerous, where they can be fastened down. In the stop-valve for the Boiler, the spindle should be constructed with a screw-thread, and be *outside*. The nut for the screw can be fastened in the centre of a bridge cast to the valve-box lid. Where the screws are inside, difficulties often arise. In all pipes fixed to the Boiler, have them so arranged that the condensed steam will drain back to the Boiler, and not go through the Engine; a great saving will be thereby produced—the hot water supplying the place of cold, according to the amount condensed. The arrangement will also, in many cases, prevent breaks-down, from the water of condensation getting into the cylinder.

XI.—Where there are two or more Boilers, do not keep any one out of action longer than is absolutely necessary for cleansing or repairs. A Boiler wears out faster when not in use, by oxydizing and corroding, than if moderately worked. It will be found more economical to work with "extra Boiler room," than to have one or more "standing." It will also tend to prevent "priming." The furnaces will be easier stoked by working a thick fire, allowing the heat to accumulate, thereby maintaining a high temperature in the furnace with slow combustion. The furnace doors not having to be so often opened as with thin-firing, the temperature in the flues will be more regular, the cooling down whilst firing much less, and the contraction and expansion also correspondingly less. By this mode of firing, furnaces will last much longer, and in the case of a Fire-box Boiler, the plates in contact with the hot

fuel will generate steam much quicker, with less labour and attention, there being an extra amount of absorbing surface in contact with the fuel, with the same area of grate.

XII.—Where the Boilers are set in brickwork, *do not use lime in contact with the iron.* In setting the bricks, use fire-clay, or common clay. Lime with damp, quickly eats away the iron; therefore do not use it at all about the metal of a Boiler. Where a "midfeather" is placed under a Boiler, it ought to be of cast-iron, in the form of a Λ, for the Boiler to rest upon. Should any leakage take place, there will be little surface for the water to lodge on. Whenever the flues are cleaned, examine the exterior and interior of the Boiler thoroughly, and do this yourself. Do this also whenever the Boiler is let off. By keeping the surface of the Boiler and the flues clean, the draught will be improved, more steam will be generated in the same time, fuel will be saved, and the Boiler will wear longer. Be your own Inspector, and become what you ought to be—a practical Engineer.

XIII.—Have a good steam-gauge to the Boiler,—one that cannot be tampered with, and one not liable to get out of order. Do not place a tap between the Boiler and the gauge: for this, by being opened and closed, will interfere with the correctness of the indications. Fix the steam-gauge in a situation where the frost or cold cannot affect it. A column of mercury is the truest indicator, when used without a floating stick, or "steam peg." "Pegs" can be made longer or shorter, to suit the convenience of the Fireman. Avoid all enclosed metallic springs, or India-rubber washers, to indicate pressure. Do not depend upon them; for the springs corrode, and lose their elasticity, while India-rubber washers become indurated—and the indications of the gauge will vary accordingly. There are various forms and makes of steam gauges; but many of them are nothing better than philosophical toys.

[In concluding this section, we would impress on all persons having charge of Steam Boilers, that there is no more certain sign of slovenliness than a dirty water-gauge or steam-gauge on the front of a Boiler, or the furnace-door covered with slime or dirt. Wherever these are met with, there is little hope of good management being found elsewhere under the same control.]

FEEDING STEAM BOILERS WITH WATER.

BETWIXT the Boiler and the Engine-pump have a self-acting stop-valve, independently of the pump, to prevent the water from returning when once it has passed the valve. It should be so placed that the

water forced from the pump will lift the valve from its seat, and allow the water to pass into the Boiler; but when the pump ceases action, the pressure in the Boiler should close the valve, and thereby retain the water which the Boiler has received.

Betwixt the self-acting stop-valve and the pump have a tap, branching from the side of the pipe. When this tap is closed, the whole of the water will pass into the Boiler; but in case the water from the pump is more than is required to supply the Boiler, the tap can be partly opened, so that one portion of the water forced by the pump may be sent through the small opening of the tap, and conveyed by a pipe to any required place, and the remainder forced through the valve into the Boiler. In proportion to the opening or closing of this tap, so will the supply of water to the Boiler be less or more. Another advantage of this arrangement is, that when no water for the Boiler is required, the tap can be set fully open, and the water will flow easily away, and offer no resistance to the action of the pump; or it can be forced into a cistern, to serve as a reserve for any purpose. The ordinary method is to have a weighted escape-valve, which requires power to force the water through—more power, in fact, than to feed the Boiler. The weighted valve also involves great wear and tear. A common inch tap will answer the purpose much better, at a twentieth part of the cost.

A small tap may be inserted in the pump bottom, or in any part of the barrel. When the pump is required to force its full quantity of water into the boiler, the tap must be closed. If no water is required into the Boiler or cistern, open the tap. Air will then be admitted, and the pump will continue to work, without lifting or forcing water, and taking little power. This is all that is required to regulate the working of the pump, and that, too, without putting it in or out of gear.

"The "Injector," for feeding a Boiler by its own pressure of steam, is now largely used, particularly for Locomotive Boilers. The greatest drawback to the use of the "Injector" is, that the water used must be cold, or not more than 80 degrees temperature, otherwise the "Injector" will not act.

EXPANSION AND CONTRACTION OF BOILERS.

A great difficulty to be contended with in the management and working of Steam Boilers, arises from the unequal expansion and contraction of parts of the structure. In some instances these are so great as to be the cause of more "wear and tear" than any other process to which the Boiler is subjected. In the "getting up" of steam, therefore, great care should be taken, otherwise a Boiler may be seriously

weakened in the process. An instance is well known where, from this cause, a Double Fire-box Boiler, when quite new, was broken quite across the bottom, or under-side, the first time the fire was applied to "get up" the steam, from the fire being urged too rapidly. This caused the internal flues to expand at a much quicker and greater rate than the outward shell; and the ends of the Boiler were thus forced outwards, until the strain tore the Boiler asunder. When the flues of Boilers of this form of construction are placed nearer to the bottom than to the top, the strain from unequal expansion and contraction is often such, that the plates of the under part of the outer shell are torn or broken; and, in other cases, leakages take place in positions where they are most difficult to discover. Whenever a Boiler has been allowed to "cool down," the next time it is worked the firing should be slow and moderate at first, so as to allow the heat to be absorbed gradually—and the evil arising from undue and unequal expansion and contraction prevented, as far as it is possible.

In the "setting" of Boilers, all the surface possible should be exposed to the action of the heat of the fire—not only that the heat may be thus more completely absorbed, but that a more equal expansion and contraction of the structure may be obtained. With round Boilers with "egg" or "dished" ends, and with the furnace underneath, too much of the surface of the Boiler cannot be exposed to the action of the fire and the heated gases. In some instances, where convenience serves, it will be found of advantage to pass the flue *over the top* of the Boiler, to equalise, in some measure, the heat, and consequently the expansion. By this mode of "setting," fuel will be saved through a more complete application of the heat, and the prevention of its escaping.

When a Boiler of the last-named description is "set" with only a small portion of its bottom exposed to the heat, and a great portion of the structure exposed to the atmosphere, as is the common practice, a powerful action is left at full liberty to work out most injurious results. The heat will assuredly expand that portion of the Boiler to which it is applied; while the other portion exposed to the cold atmosphere will as assuredly contract. Thus the two forces are left to exert their respective powers *against* each other—tending to tear the Boiler asunder, by means almost imperceptible; and the ultimate result is not unfrequently a Boiler explosion, in spite of the fact that a structure in this form is the strongest possible, excepting the truly spherical.

In the construction and fixing of a Boiler, there are other matters that require attention. Parts where the plates overlap should be exposed as little as possible to the direct action of the fire. Where this point is neglected, the outer plate is in danger of being burnt and

weakened, until in the end leakage is caused, and the plate is rent, both these tending to the destruction of the Boiler.

The thickness of the plates of which a Boiler is composed is of importance in other respects besides that of requisite strength for the working pressure required. It is commonly supposed that a thin plate allows heat to pass through it into the water within, quicker than a thick plate can do. This is true, so far as getting the water heated to the boiling point. The Author has found, by direct experiment, that in a Boiler formed of plate one-sixteenth of an inch thick, water was brought to the boiling point in half the time it could be accomplished in a Boiler formed of plate three-eights of an inch thick, all other circumstances being the same. But he found, also, that when the fire in the respective cases had been three hours at work, the Boiler formed of the thick plate had evaporated much more water than the one formed of the thin plate. Repeated experiments were invariably followed with the same results—showing the advantage of a moderately strong plate for the flues and furnace portion of a Boiler. The Author has found half-inch plate to be a desirable thickness for the fire-box and flues of Cornish Boilers, having regard to strength, economy, and durability. It may not be amiss to observe also, that the quality of the iron, and the character of the workmanship are also necessary things to be attended to, in the construction of a Boiler.

Another matter to be observed in relation to a Boiler at work, is the unequal pressure to which its several parts are subject at the same time. Take, for instance, a Fire-box Boiler, working at 50lbs pressure to the square inch. That would be the pressure exerted on the upper side of the flues, slightly covered with water. Suppose the flues to be three feet in diameter, on the under side of those flues the pressure would be 51½lbs to the square inch—the weight or pressure of the column of water having to be added to the steam pressure of 50lbs. It is from this fact, that the pressure is necessarily greater on the under-side than on the upper side of internal flues, that, in cases of giving way from over-pressure, such flues crush *upwards* much more often than they crush *downwards*. There are also other actions going on in a Boiler of this construction, which add to this tendency—the strain and tension produced by unequal expansion and contraction. This is aided, too, sometimes, by the ignorance of the Boiler maker, of which an instance was given by one at Stockport, who constructed a Boiler with an oval internal flue, and who stayed the upper side of the flue, but not the under side, where the largest amount of pressure necessarily had to be sustained—probably from a notion that the only pressure to be provided against, at that part, was the weight of the water.

The Boiler exploded—the flue crushing *upwards:* and seventeen lives paid the forfeit. However ridiculous it may appear to suppose that such a notion as the one described above could be entertained by a Boiler-maker, the fact was sufficiently illustrated in the case of the Boiler explosion at the Castle Mills, Sheffield, some years ago. The first time that steam was "got up" in the Boiler in question, the bottom portion of the flat end at the back, below the flues, gave way, and the Boiler was sent like a rocket out of its seating, right across a public street, smash through some buildings on the opposite side of the street to the Mills, and on into the river Don—four lives being lost. On an examination of the Boiler, the Author found that the flat ends had not been stayed at the bottom portion, where the greatest pressure would necessarily be; and on the Boiler-maker being spoken to regarding this serious defect in construction, he excused himself by observing he did not think the Boiler required staying in that part, because where there was no steam there was nothing but water, and consequently no pressure. Nothing possibly could be more absurd; and the two cases, out of many that could be adduced, show the necessity for all the parts of a Boiler being made suitable for the various strains to which the structure is subjected when in use.

The accompanying engraving, Diagram No. 1, illustrates in a remarkable manner what has just been enforced—and illustrates also the tremendous effects produced on the structure known as the Boiler, by a Boiler explosion. The drawing represents the blown-out flue of a Steam Boiler, taken exactly as it lay after it had been sent with artillery-force out of the Boiler, through the wall of the Boiler-house, and across a wide goit of water into a passage on the other side, near to where there was another Boiler at work, which narrowly escaped destruction from the flying missiles—the large stone shown in the foreground of the engraving having been sent through the wall of this second Boiler-house, with one of its corners impinging on the Boiler at work, producing a large and deep indentation. In this case also, the flat ends of the Boiler were only stayed on the upper side. We shall subsequently refer more at large to this engraving, and the positions it illustrates.

This brings us to another subject connected with the working of Steam Boilers, viz: whether the iron of which the Boiler is composed is stronger—that is, better able to resist tension or a crushing force—when cold, or when heated up to the ordinary temperature of a Boiler when at work, according to the pressure of the steam—or from 212° to 300°, or more. At a Coroner's Inquest held in Leeds, on the occasion of a Boiler explosion in the neighbourhood, the following question was put to an Engineer—a witness called to show the *cause* of the explosion:

"Do you consider the Boiler to be stronger, or weaker, when heated by the pressure and temperature of the steam?" Answer: "I consider that the Boiler is much weaker when the temperature is increased, than when cold." Question: "How much with steam at 50lbs pressure?" Answer: "Twenty-five per cent." It is lamentable that ignorance like this,

Diagram No. 1.

TORN BOILER FLUE, AT UPPER ASPLEY, HUDDERSFIELD.

A. Interior of Flue—cylindrical when in Boiler. B. Form of under side of Flue, crushed *upwards*.
C. Gusset Stay, attached to Flue.

though put forward with all the assurance of professional dogmatism, should pass current in a Court charged with a most important and delicate inquiry—an inquiry into the cause of death consequent on a Boiler explosion. The very reverse of that deposed to, was the fact: for

iron, when heated up to about 600 degrees, increases in strength up to that temperature—that is, it increases in power to resist tensile strain, or to carry weight, up to the temperature named; and this is therefore held to be the point where the maximum strength of iron is attained. Thus, the internal flue of a Boiler at work, where the upper side is necessarily at a higher temperature than the under side, is the weakest in the latter part, as the result of two actions : first, less temperature—and second, higher pressure, as before shown. Here, then, in the matter of difference of strength arising from difference of temperature, we have another cause to account for the fact that Boiler-flues, in cases of explosion from over pressure, are more often crushed in from the under than the upper side. The two actions we speak of, which are continually in operation when a Boiler is in use, tend to force the flue out of the form in which it was first made—and thus, as it departs more and more from the perfect cylinder, to become weaker and weaker.

THE FORM, STRENGTH, AND STAYING OF BOILERS.

THE Double Fire-box, or Flue Boiler,—the form now in most extensive use,—is generally formed of three tubes—two lesser, and one larger. The two lesser are placed within the larger, and all are bound together by end flat plates. The space around these tubes, and between them and the outer shell, constitutes the water space and the steam chamber. The pressure, whatever it is, which the steam exerts within the Boiler, is exerted *within* this space—that pressure being *internal* to the large or outer shell, and *external* to the smaller inner tubes or flues. That pressure also, whatever it may be, is exerted upon the flat ends of the Boiler. This form of construction, which is the prevailing and favourite form, is not only not safe without careful staying, but positively and of necessity unsafe; and it follows, as a matter of course, that with the high pressures now worked at, this want of safety becomes in many cases absolute danger; while, with all Boilers of this construction, unstayed, and at whatever pressures they may be worked, if that pressure be appreciable, their giving way is but a question of time.

The great source of danger in this form of Boiler is the inner tube or flue, and the flat ends. When pressure is exerted within a tube or cylinder, with spherical ends, the tube can only give way by the metal being torn asunder; and the tendency of the strain is to cause the tube to assume the true cylindrical figure, or spherical form—the form of greatest resistance. With pressure exerted on the *outside* of a tube, the tendency of that pressure is to crush in the tube—to flatten it.

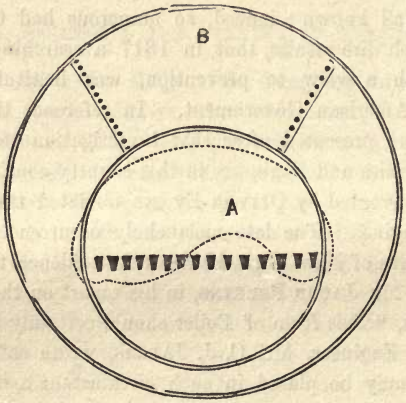
It is a well-known fact that iron of any strength, when formed into a tube, will bear a much greater strain to tear it asunder if that pressure be applied *internally*, than it will bear without crushing in, when applied *externally*. A bar of iron, when used as a tie-rod, will resist a very large amount of tearing force; but that same bar placed as a prop only under the weight exerted in the former case, would be doubled up, and crushed out of form. The inner tube of a Boiler of this construction is but a series of props placed to sustain the immense weight of the pressure exerted externally to its diameter. The constant and never-ceasing tendency is for those props to give way—for the cylindrical tube to depart from the form of greatest resistance—to become flattened or bulged; and its ultimate crushing-in is, in the best of cases, where proper staying has not been resorted to, only a question of time.

The Double Fire-box Boiler was invented in America by OLIVER EVANS, and was for a considerable period, and in some parts is still, known as OLIVER EVANS' Boiler. It was used in America so far back as 1786. Boiler explosions have been by no means uncommon in America, as is well known; indeed, so numerous had they been, and attended with such dire results, that in 1817 a searching enquiry into their cause, with a view to prevention, was instituted under the sanction of the American Government. In reference to the Fire-box Boiler, the report presented after that investigation states :—"Many respectable Mechanics and Engineers in this country considered that the improved Boiler invented by OLIVER EVANS obviated the objections to High-pressure Engines. The late melancholy occurrence on board the *Etna*, in the waters of New York Harbour, is evidence that they have been deceived." Mr. JACOB PERKINS, in his report on the same form of construction, says, "This form of Boiler should certainly be abandoned." Another eminent Engineer, Mr. C. J. JARVIS, wrote as follows :—"A flue of this kind may be placed in such circumstances, that when the steam and temperature get unusually high, it suffers a minute change of form. Under these circumstances it will inevitably collapse sooner or later, according to the extent to which its form is altered at each time it is unusually heated and the frequency of that occurrence, let it be surrounded with as much water as it may."

There is no doubt that, providing the flues were strictly cylindrical, their strength would be very great; but such is not the case, nor is it possible to make them strictly true. The very weight of the material itself is sufficient to destroy the true figure of the flue, even providing it were made of one whole plate without rivets or lap joints; but in the ordinary flue, as used in all Boilers, the figure of greatest resistance is let go at once by the overlapping of the plates. In the case of horizontal

tubes, as employed in Steam Boilers, the pressure is not uniform ; for, as has been already shown, while the pressure on the top part of a flue, three feet diameter, may be 50lbs per square inch, the pressure upon the under side would be 1½lbs more ; because the weight of the column of water has to be added to the pressure on the lower part of the tube. What should be the cylindrical figure in that case is not the true figure of greatest resistance. We therefore need not be surprised at the explosions which occur from collapse of flues, when not properly stayed. The very form almost seems to invite the occurrence. It is by a continued working of such description of Boiler, and the always increasing weakness of the flue, from its varied pressure and temperatures, and its consequent change of form, that explosions ultimately occur. Hence the reason why a tube that has been tested to a pressure of 80lbs or 100lbs to the square inch may afterwards fail under a pressure of less than half that amount.

Diagram No. 2.



CROSS SECTION OF BOILER, UPPER ASPLEY, HUDDERSFIELD.

A. Internal Flue, three feet diameter.
B. Outer Case of Boiler, five feet diameter.

☞ The dotted lines on Flue show the form the Flue assumed when crushed *upwards*, as shown in Diagram No. 1.

The accompanying Diagram, No. 2, is here given to illustrate what has just been advanced. It is from an exploded Boiler—the blown-out flue being shown by Diagram No. 1. The one now presented illustrates the general form of constructing the Cornish one-flued Boiler, showing the relative sizes of the two tubes of which the Boiler is composed, and also their relative position. A is the inner tube, or flue, open at each end ; B is the outer tube, or case, closed at each end by the flat plates placed

between the inner edge of B and the outer edge of A. The inner circle, A, shows the form of the flue as originally made, and when at work. The small dotted lines on this inner circle show the form that flue assumed when it was *crushed upwards* by over-pressure, and sent out of the case like a tremendous bolt from a monster gun, torn, jagged, and rent in all directions, as shown by Diagram No. 1. The two lines of larger dots, radiating from the outer edge of A to the inner edge of B, indicate the position of the two gusset-stays placed at the fire-box end of the Boiler.

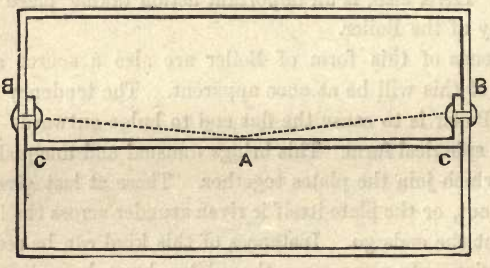
It has already been pointed out that there are other changes in connection with this form of Boiler which cannot altogether be prevented from taking place. Plates crack and give way on the under side of the Boiler from unequal contraction and expansion, caused by the difference of temperature of the top and bottom side of the Boiler. A Boiler also is materially hastened in its destruction by the emptying of it while hot, and then suddenly cooling it by admitting cold water, to get off the scale. Double Fire-box Boilers have been fractured on the under side, both in the line of rivets and even across the plates, from this cause. Observe also, when starting a Boiler and getting up the steam, and notice the length of time the water on the under side of the flue is before it is even lukewarm. Here, also, is an important action taking place in reference to the safety of the Boiler.

The flat ends of this form of Boiler are also a source of weakness. The reason of this will be at once apparent. The tendency of the force within the Boiler is to cause the flat end to bulge outwards—to assume, in fact, the spherical form. This brings unusual and unequal strain upon the rivets which join the plates together. These at last give way, being either torn out, or the plate itself is riven asunder across the line of rivets, and then out the ends go. Instances of this kind can be seen in almost every explosion. In some cases the plates have been torn asunder as though they were but paper. When once any part of a Boiler gives way the other parts become exposed to unequal strain from the expanding contents, which exercise a tearing and impelling force equal to that of gunpowder.

To counteract this tendency of the flat ends bulging outwards, it is usual to *stay* them. Stays, at best, are but inferior substitutes for the form of greatest resistance. Stays would be of no service applied in a sphere subjected to internal pressure ; the power of resistance would be exactly that of the metal to sustain the strain, exerted upon all parts alike. Stays could be of no advantage in such a construction unless they could be applied so as to strengthen that metal in all its parts ; and this, as will be seen at once, could only be accomplished by using metal of greater thickness or strength for the original construction.

Boiler stays, therefore, are at all times but a substitute for real strength of construction ; but the manner in which they are almost invariably applied renders them insecure, and, at times, positively dangerous, because they incite to the idea of security where it is in reality absent. Diagram No. 3 illustrates the common method of applying stays inside a Steam Boiler. The reader is to suppose that the outer lines of the engraving represent a section of a cylindrical Steam Boiler, and that the straight and continuous lines across the centre, marked A, represent an iron stay rod, proceeding from end to end, to counteract the tendency of those flat ends to bulge outwards, or be blown off with the internal pressure. It will be at once apparent that if we desired to secure the utmost benefit this stay-rod is capable of rendering, we should let it proceed *through* each end of the Boiler, in a direct line with its own length ; and then by means of washers, screws, and nuts, secure it in that place. The strain would then be direct to its own length, and its power of resistance would be equal to the weight applied perpendicularly which the iron rod would sustain without tearing asunder. But stays are scarcely ever thus applied. The Diagram illustrates the usual mode of application.

Diagram No. 3.



Instead of proceeding through the Boiler-ends, the stay-rods are bent at a right angle, and riveted or bolted to the Boiler through the bent parts, as shown at B B of the Diagram. The strain, as will at once be seen, is mainly *on the bent portions of the stay* : and the tendency is for those bent portions to straighten out. Instead of the pull being in a direct line to the length of the stay-rod, as would be the case if applied as before described, the pull from each end is in the direction of the dotted lines from B B to A, and the constant tendency is for the rod to leave the Boiler-ends at C C, and for the end to bulge out by all the length the rod can obtain by straightening at those angles. This is on the supposition that the rod does not break at those angles or across the rivet holes—the weakest part, but on which there is the greatest strain, and that a

bending one; and also supposing that the rivets or bolts do not give way. When we apply tie-rods to a floor or a roof, or to a beam of any kind, we do not copy the mode of application adopted with Steam Boiler tie-rods; we apply them so as to secure the full power of their resistance against strain or weight; and we ought also to do so in the case of Steam Boilers.

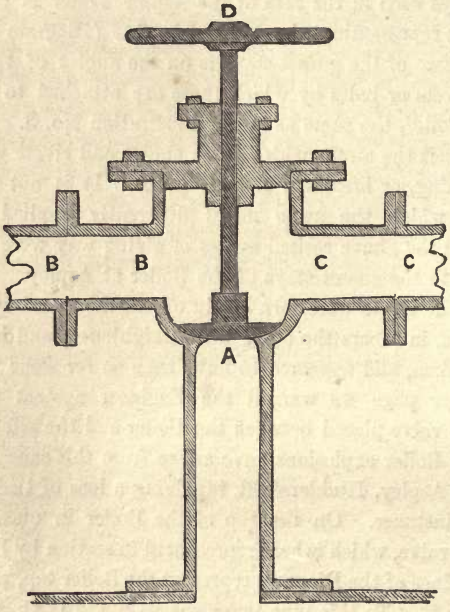
The principle of application appertaining to the gusset-stay is precisely that just described and illustrated. It is formed, as before stated, of angle iron and a gusset of boiler plate. An accurate representation of the actual stays used in the case of the Aspley Boiler is given at C, in the engraving representing the crushed-in flue (Diagram No. 1.) The strain in the case of the gusset-stays is on the angles of the angle-irons, and on the rivets or bolts by which these are attached to the ends and sides of the Boiler, the same as in our illustration No. 3. The power of resistance is just the strain which these angles and rivets will bear without straightening, or breaking, or tearing out. It is not by any means the amount which the same metal differently applied would give. Samples of all the above recited modes of giving way were to be seen in connection with the gusset-stays of the Boiler at Aspley. In some cases the heads of the rivets were torn off, in others the metal was torn across the rivet holes, in others the angle was straightened, and in another the angle was broken, and appeared to have been so for some time.

In a former page we warned the Engineer against the danger of having a stop-valve placed between the Boiler and the safety, or blow-off, valve. Many Boiler explosions have arisen from this cause, of which the one at Upper Aspley, Huddersfield, involving a loss of twelve lives, was a memorable instance. On the top of the Boiler in question there was affixed a stop-valve, which is here represented in section by Diagram No. 4.

The lower lines of the Diagram represent the Boiler top, with the pipe A standing upon it. To this pipe two arms, B B and C C, were attached, these also being pipes. B B led to the safety-valve, which was placed at a considerable distance from this point; and C C led to the Engine. At A, a stop-valve was placed, its seat being BELOW BOTH THE APERTURES, B B and C C. This valve was worked by a wheel and screw, represented at D. When the valve was open, the part which in our Diagram closes the passage at A, was raised up *above* the openings of the cross-pipes B B and C C, and then allowed the steam to pass either way, either to the Engine or to the safety-valve, or to both. When the valve was closed, it was screwed down as now represented at A, completely "bottling up the Boiler," and preventing all escape of the steam, except by rending the Boiler asunder! This was the exact state of this stop-valve—stop-valve up to a point indeed it proved to be!—and of the

Boiler at the time of the explosion, and the state in which it had been for some time, perhaps for nearly an hour, before the explosion. This it was that prevented the steam from passing to the Engine, and induced the attendants to conclude that "the steam was down." Hence the injunctions to "fire up," although danger then existed; and hence also the *firing*, until the limits of resistance within the Boiler had been passed. Hence also the catastrophe and its fatal results!!

Diagram No. 4.



PLAN OF STOP-VALVE ON UPPER ASPLEY BOILER, IN SECTION.

A, Pipe proceeding from Boiler. C C, Feed-pipe to Engine.
B B, Pipe proceeding to Safety Valve. D, Wheel and Screw to raise and lower Stop-valve A.

The Inquest held on one of the twelve persons killed from the cause above detailed, was attended by Mr. WILLIAM FAIRBAIRN, C. E., in a professional capacity; and he on that occasion recanted, in a great measure, his former teachings in relation to the strength or power of resistance of the internal flues of Boilers, with the pressure exerted externally to the diameter. His evidence on this occasion was:—"I may mention that I have recently been making some experiments with regard to the collapse of tubes. It was found that some flues collapsed unexpectedly,

and when according to our ideas, they ought not to have collapsed. This induced a series of experiments interesting and conclusive. The Royal Society of London made me a grant for these researches. I took a Boiler of 36 feet, with a flue of three feet diameter, and another of 18 feet long, and I found that the long flue will go with half the pressure of the short one : that the strength is inversely as the length. I must confess that previously myself and other Engineers thought that the length made no difference at all ; but I find that the strength of all Boiler flues, all tubes whatever, whether of iron or copper, follow a certain law, that the resistance is inversely to the length."

In relation to the explosion itself, Mr. FAIRBAIRN said in his report : "It will not be necessary to enter into calculations as to the forces generated in the Boiler, which led to such unfortunate results. Suffice it to observe that the flues and the ends were the weakest parts, and the first to give way. The former collapsed from compression on its exterior surface, and the fracture which gave vent to the elastic power of the pent-up steam was quite sufficient to account for the results that followed —namely, the demolition of the buildings, and the projection of the Boiler, flues, &c., into the positions in which they were found."

The result of a most searching, patient, and extended enquiry was the following verdict :—"The jury find that the death of Joseph Lum was caused by the explosion of a Steam Boiler, the explosion resulting from the screwing-down of a stop-valve, placed on the top of the Boiler, which when closed, completely cut off all connection with the safety-valve ; but who closed that stop-valve, the jury have no evidence before them to show. But the jury, in returning that verdict, cannot but record their *strongest condemnation* of that combination of stop-valve and safety-valve which put it in the power of any one at any time to prevent the action of the safety-valve by merely closing the stop-valve ; and the jury consider that the Engineers who applied this dangerous construction are highly censurable, as is also the proprietor of the Boiler, who permitted it."

With regard to the strength of iron, the table which follows is the result of a series of tests conducted by Messrs. ROBERT NAPIER & SONS, of Glasgow.

STRENGTH OF WROUGHT-IRON BARS AND IRON PLATES,

BY MESSRS. ROBERT NAPIER AND SONS.

IRON BARS.

	Tenacity in lbs per sq. inch.		Tenacity in lbs per sq. inch.
Yorkshire: strongest	62886	West of Scotland: weakest ...	56655
„ weakest ...	60075	Sweden: strongest	48232
„ (forged)	66392	„ weakest	47855
Staffordshire: strongest ...	62231	Russia: strongest	56805
„ weakest	56715	„ weakest	49564
West of Scotland: strongest	64795		

IRON PLATES.

Yorkshire: strongest lengthwise	56005	Yorkshire: strongest crosswise	50515
„ weakest lengthwise	52000	„ weakest crosswise	46221

NOTE.—The strongest lengthwise is the weakest crosswise, and *vice versa*.

According to these tests, Staffordshire bars were nearly equal to those from Yorkshire. Yorkshire Boiler Plates vary from the strongest, lengthwise, 56,005, to the weakest, crosswise, 46,221. These figures would represent the tenacity, or the resisting power of a Boiler, supposing that the plates were *welded* together; but as this is not practicable, one-half, or thereabouts, of the resisting power is *cut away* by the formation of rivet-holes. The strength of the Boiler is thus at once reduced to 23,110, or *half* the strength of the plate; and this, too, on the supposition that the rivet-holes in the plates are bored. In the case supposed, this rule would apply; but in the ordinary way of Boiler-making, the rivet-holes are not bored, but *punched* out of the solid cold metal by powerful machinery. This *punching* to a great extent *impairs the tenacity of the remaining portion of the plate betwixt the holes.* Then follows another process more injurious than the former—what is technically called "drifting." This "drifting" is a process whereby the holes of one plate are made to correspond with the holes of another plate, when the plates are in progress of being riveted together. When the holes do not exactly meet each other, so that the rivet will pass easily through both, the Boiler-maker uses an instrument called a "drift." This is a taper "mandril," which is driven into the two holes, and widens them out by the force of blows with the hammer. It often happens that the metal betwixt the holes at the edge of a plate is "cracked" with the "drifting"—in many cases weakening, and in others so far destroying, the tenacity of the remaining metal, that the strength of the remaining portion cannot be taken at more than 20,000lbs. In some instances where the plate in its process of manufacturing has had but little cut from its edges, when being "squared up," the edges of the

plate are quite brittle ; and then, what with the before-mentioned mode of punching, and what with bending the plate in a cold state, such plate may be frequently seen "cracked" from hole to hole. From these and similar causes, a Boiler is often more than half destroyed before it leaves the Boiler-maker's yard.

In the process of bending Boiler Plates cold, the fibres of the metal are stretched, and their tenacity impaired or destroyed. Were they passed between bending-rollers, when heated to a proper working heat, the fibre would be properly drawn out, and its tenacity preserved—the same as in any other process of forging or shaping wrought iron. There cannot be a doubt that in the case of Boiler-flues bent cold to diameters varying from two feet to three feet, the plates are thereby weakened to a great extent. So long as the present mode of Boiler-making is pursued, we shall have weak and defective Boilers. The expense of heating the plates, for the purpose of bending them without injury, would be trifling. And there would be another resulting advantage : if there were any "flaws" in the metal, these would sooner show in the plate when in a heated state, than when bended in a cold state.

The suggestion has often been thrown out, that were the rivet-holes of Boiler Plates bored instead of being punched, one part of the evil above pointed out would be remedied. There is no doubt but that process would be a great improvement upon the present practice ; and if some independent firm would make Boilers with the same care and attention to material and workmanship as is done in Steam Engine construction, they would command a trade, although their prices would necessarily be higher than those who "make" in the ordinary manner. To the user, Boilers thus carefully built would be much cheaper in the end, to say nothing of the reduction to risk of life—the loss of which cannot be compensated for ; and this to the humane is a consideration of importance.

The rule laid down for the strength of Steam Boilers, taking the tenacity of the plates at 60,000, is, according to the tests of the Messrs. Napier, far too high ; and considering the before-mentioned methods of Boiler-making, we ought not to calculate the resisting power of Boilers at more than two-thirds the amount we have been in the habit of calculating. That is, instead of calculating the tenacity at 30,000lbs, we should not calculate that tenacity at more than 20,000lbs. Thus, the bursting pressure of a tube 30 inches diameter, made of $\frac{3}{8}$ inch plates, under the old rule, would be 750lbs to the square inch ; according to the new rule it would only be 500lbs to the square inch. This new rule will be much nearer to the truth in practice than the former rule ; and the tube would also require to be of good material, and well made, to resist 500lbs to the square inch.

Whatever may be the strength of Boiler Plates before they are worked into shape, if care and attention are not paid to the bending, punching, drifting, and riveting, the best iron will become comparatively valueless. With the best material, the strength of a Boiler must greatly depend upon the manner in which it is made, and the care used in its construction, even if its form be correct in principle.

RULE FOR CALCULATING THE STRENGTH OF CYLINDERS OR BOILERS, AS GENERALLY APPLIED.*

The tenacity of the metal of which a Boiler is constructed is about 60,000lbs, or six-sevenths that of good wrought-iron—a bar one inch square being the standard.

As, however, the cylinder which constitutes the Boiler is not whole, or *in one piece* welded together, but is composed of a number of plates riveted together—the plates also being cut away for the holes—it will be necessary to diminish the number which expresses the tenacity. Let, therefore, the tenacity be put at 30,000lbs, in place of 60,000lbs.

Multiply the numerator of the thickness by the tenacity of the metal, and multiply the denominator by half the diameter of the cylinder in inches ; then divide the numerator by the denominator, and the quotient will give the strength of the cylinder, or bursting pressure.

EXAMPLE I.

Take a cylinder 30 inches diameter, made of $\frac{3}{8}$ inch plate: thus—

$$\frac{3}{8} \times \frac{30{,}000}{15} = \frac{90{,}000}{120} \text{ then } 90{,}000 \div 120 = 750\text{lbs, the bursting pressure.}$$

EXAMPLE II.

A cylinder of six feet diameter, made of $\frac{1}{2}$ inch plate: thus —

6 feet = 72 inches

$$\frac{1}{2} \times \frac{30{,}000}{36} = \frac{30{,}000}{72} \text{ then } 30{,}000 \div 72 = 416 \text{ and } 17\text{-}18\text{ths lbs., working pressure.}$$

* This rule is the one generally acted upon, and is no doubt pretty nearly correct, when the metal is without flaws, and the workmanship without defects. But as these cannot always be relied upon, the rule and the deduction from it will be found to be far too high for ordinarily made Boilers.—[See observations and deduction on preceding page.]

TESTING BOILERS.

THE utility of testing Boilers to an extreme, or to considerably more than the strain sustained in actual use, is more than questionable. Practice has taught that it is better not to test Boilers, beams, or bars of iron, with more than the ordinary strain required. We may, by an extreme test, prove that the article tested has withstood such and such a strain : but we do not know how such strain may have injured the substance tested. For instance, a cast-iron beam was tested at the foundry of Messrs. MILLBURN'S, Staleybridge. The beam was 27 feet long. A weight of 24 tons was hung on the centre, with which the beam deflected $1\frac{1}{8}$ inches. When the weight was removed, the beam assumed its former form. The same beam was shortly afterwards tested with 16 tons hung on the centre, when it broke—though there were eight tons less than it had withstood before.

Another instance was afforded in the test of a Steam Boiler at Messrs. HARGREAVES, at Accrington. The hydraulic test was resorted to. The extreme working pressure of the Boiler was a little under 40lbs to the square inch, and the test the Boiler was submitted to was 70lbs to the square inch. To all appearances, under the test the Boiler was safe at that pressure. In about three months after this testing, the Boiler exploded ; and on investigation, there was sufficient to show that the test to which the Boiler had been subjected injured the structure—and from that time till the whole gave way, the Boiler had been gradually getting weaker. The flues had been strained by the test, the pressure being on the outside of the diameter.

There can be no doubt that the testing of any structure or machine to the full strain the apparatus may be expected to resist, is highly necessary ; but beyond *that*, there is more risk of injury to the apparatus tested, than any chance of good resulting from an extreme test.

The word " test " carries with it to the theorist and the casual observer an idea of security—because such test affords proof that the machine or structure has withstood a certain force. This may be quite true : but it does not follow that the same machine or structure will resist the same amount of force again, or anything approximating to it.

CLEANSING BOILERS.

It is well known that water impregnated with earthy matters produces, when boiling in a Steam Boiler, a scum on the surface. If this scum be collected and blown out, the Boiler will seldom require to be opened and cleansed ; but if the scum be allowed to accumulate and settle upon the

Diagram No. 5.

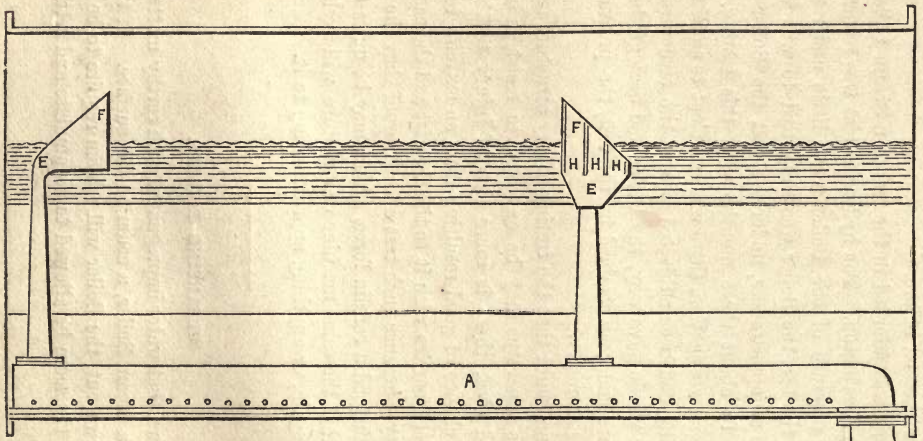
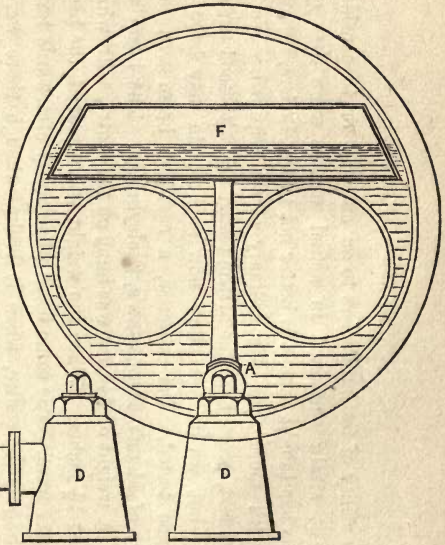


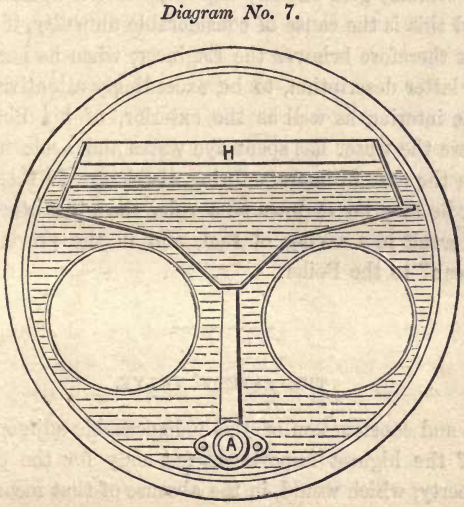
Diagram No. 6.



plates where the fire impinges, the injury to the Boiler will be in proportion to the thickness of the accumulation, which, according to the nature of the deposit, assumes the form of scale, or mud. When it assumes the first-named form, the Boiler will require to be often opened and cleansed, or the injury from the burning of the plates will be great.

An arrangement has been patented by Mr. NEEDHAM, of Duckinfield, near Manchester, for the collection and riddance of the scum, or deposit. His apparatus consists of a number of hopper-like mouthed vessels, introduced into the Boiler standing a little above and below the water-line. These vessels communicate, by means of vertical pipes, with a horizontal pipe that passes through to the outside of the Boiler. As the scum arises, and falls again in the water, the open-mouthed vessels collect it; and, as at intervals, the valve at the end of the pipe spoken of is opened, the collected scum or deposit is "blown out," and the Boiler plates are thus kept clean. See Diagrams Nos. 5, 6, and 7.

Diagram No. 7.



In the above diagrams the longitudinal pipe, extending from end to end, is shown at A, which is perforated with two rows of small holes, communicating by the elbow pipe, C, to the cock or valve, D. At the top of the longitudinal pipe, A, there are vertical pipes, E, each mounted by a cast-iron funnel, F, at the level of the water, the mouth of which faces the front, or firing end of the Boiler. The cast-iron funnel in Diagrams No. 5 and 7 is supplied with elevated partitions, H, leading to the receiving chamber at the top of the vertical pipe, E. The heat from the firing end causes a continual roll or flow of water towards the

back end, by which means the scum enters the funnels, from whence, by opening wide the cock, or valve, D, it is swept away into the sewer or drain. The apparatus can be so modified as to suit every description of Boiler, whether multitubular, two-flued, or egg-shaped; and in adapting it to the Boiler, the latter requires no cutting. Any length of Boiler can be cleansed from end to end in less than one minute, without stopping the working.

There are other modes of collecting the scum,—namely, by open trays placed in the Boiler; and also by a pipe from the bottom of the tray to the outside of the Boiler, with a tap. By opening the tap, the heavy matter collected in the trays is blown out. Mr. Robert Armstrong, formerly of Manchester, applied the tray principle to Boilers more than thirty years ago; since then, various modifications have been adopted, and improvements made—as shown by Mr. Needham's plan.

In water there is a great difference in quality for Steam Boiler purposes. Some waters scarcely give out any deposit, while with others the deposit is great; and this is the cause of considerable difficulty, if not constantly removed. It therefore behoves the Engineer, when he has to work with water of the latter description, to be exceedingly attentive, and to look well after the interior, as well as the exterior, of his Boiler: and particularly where the water has spent-dye wares and acids mixed up with it, as is often the case in manufacturing districts. In this matter, as in many others, he may lay it down as a rule, that the utmost cleanliness possible will result in a saving of fuel, and in the prevention of much "wear and tear" to the Boiler.

THE SAFETY VALVE.

The form and construction of this indispensable adjunct to the Steam Boiler are of the highest importance, not only for the preservation of life and property, which would, in the absence of that means of "safety," be constantly jeopardised, but also to secure the durability of the Steam Boiler itself. And yet, from the manner in which many things called Safety Valves have been constructed of late years, it would appear that the true principle by which *safety* is sought to be secured by this most valuable adjunct, is either not well understood, or it is disregarded by many Engineers and Boiler-makers. Many of those unfortunate calamities—Boiler explosions—have occurred when, to all appearance, the Safety Valves attached have been in good working order: and Juries under the presidency of Coroners, have not unfrequently been puzzled, and sometimes guided to erroneous verdicts, by scientific evidence adduced

before them, tending to show that nothing was wrong with the Safety Valves—and that the devastating catastrophes could not have resulted from over-pressure, because in such case the Safety Valve would have prevented them.

If the inventor, Dr. PAPIN,* of that most useful and scientific apparatus, the Safety Valve, could but witness some of the forms given to the instrument, and some of the modes of construction adopted, he would indeed marvel to see the degeneracy which, in this day of general improvement, is but too often apparent in the manufacture and construction of this essential and indispensable adjunct.

The portions numbered 1 and 2 on the accompanying engraving, page 28, represent variations of the Common, or Mushroom Valve. This is usually constructed with a guide-pin, to pass through a hole or socket provided in the cross-bar inserted in the seating of the Valve—such guide-pin and steadying-socket being *underneath* the Valve, and consequently *within* the Boiler, constantly and fully exposed to the action of the steam, the varying temperatures, and to the accumulations of dirt and other extraneous matters. With this form of construction alone, numerous Boiler explosions have occurred—from the stem, or guide-rod, of the Valve having got bent, or otherwise damaged; from its having become corroded in the steadying-socket of the cross-bar; from its becoming fast in its place, when closed; or from many other and obvious causes. It is clear that when the Mushroom Valve is in any one of these states it is impossible for it to act, and the Boiler is then, to all intents and purposes, as if nothing in the shape of a Safety Valve had been provided.

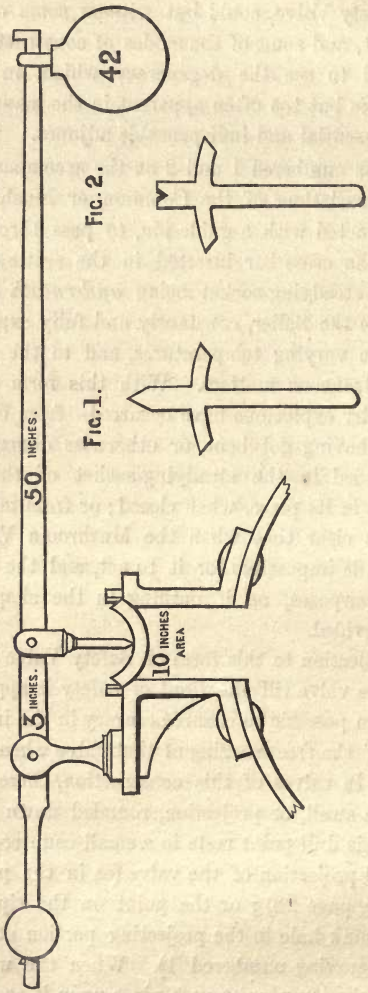
Another objection to this form of Safety Valve is, that the weight to keep down the valve till the limit of safety is approached, is applied in the worst form possible to ensure accuracy in the indications of the valve, or to allow of the free working of that valve when over-pressure requires it to open. In valves of this construction, there is generally provided on the lever a swell, or projection, rounded down at the end to a dull point; and this dull point rests in a small counter-sunk hole in the outer tip, or central projection of the valve (as in the portion numbered 2 of the engraving, page 28); or the point on the tip of the valve rests in the counter-sunk hole in the projecting portion of the lever (as in the portion of engraving numbered 1). When the weight is hung on the other end of the lever, or at such place upon it as has been arranged for, the swell, or projection, on the lever bears upon the tip of the valve, and keeps that valve down on its seat until it is raised therefrom by over-

* Dr. Denys Papin, a native of Blois, in 1680, invented the common Lever Steam Valve, misnamed the "Safety Valve."

pressure of steam within the Boiler. But it is a question arising from this mode of applying the weight, whether the valve *can* act at the time and in the manner designed. In the first place, the joint at the end of the lever, where it is attached, must necessarily have some play given it.

Diagram No. 8.

LEVER SAFETY VALVE.



Oftentimes greatly too much is given ; or rather, no care to have exactness of fitting is exercised. This play, from the action of the lever and wear and tear, becomes greater and greater ; and every departure from exactness, either in the original manufacture, or from subsequent wear,

takes the weight from the *centre* of the valve, and brings it more upon one or other of its sides than the rest. These deviations from exactness may be small, almost infinitesimal, in themselves : but multiplied as they are in fact, in the ratio of the length of the lever from its attachment to the point of bearing on the valve, they become anything but inappreciable, or non-detrimental to the free action of the valve. When the valve is thus weighted out of its centre, two separate but injurious actions take place : first, when over-pressure occurs, instead of the valve being lifted bodily from its seat, it becomes tilted, and the steam escapes at *one side* only : and second, in consequence of this tilting, the guide-rod often becomes bound fast in the guiding-socket of the cross-bar ; and the valve is thus prevented from operating, except in a very limited degree—not nearly sufficient in cases of over-pressure. The worst is, that under the circumstances supposed, the higher the pressure—that is, the greater the danger from which the valve is required to relieve—the less capable does it become of operating in the manner for which it was calculated and designed : for the greater the force brought to bear upon the tilted portion of the valve—(and be it remembered that this tilting exposes more of the surface of the valve-face on the tilted side than on the side which still remains covered by the seating)—the more firmly does the valve become bound in the guiding-socket. From these and other causes of a similar nature, Safety Valves of this construction cannot be made to work accurately—and they are totally inapplicable for high pressures, if " safety " is to be a consideration. The indications, however carefully the valves may have been weighted, are often most inaccurate. The Author has known valves of this description to be kept as perfectly down to their seatings as they are capable of being kept—that is, without any escape of steam from over-pressure—when the pressure in the Boiler, as measured by a more accurate test, has been 12lbs more than the valve was calculated and weighted to blow off at. With a valve of this description, any one, by moving the lever to and fro, may cause the steam to escape at either of its sides. To counteract this tendency to tilt, other guides have at times been applied ; but it has been found in practice, that this attempt to remedy one evil has only been to create others, which equally tended, and in like manner, to prevent the proper and safe working of the valve.

The main portion of the accompanying engraving, (Diagram No. 8,) is a representation of a Safety Valve which has been designed and introduced to prove that a valve of the ordinary kind may be made to act well, generally speaking—to blow off from over-pressure, with far greater accuracy than either of the constructions before considered, and also with a uniform discharge of steam from all sides of the valve orifice,

when open. The valve is of the spherical form on its under side; and it is placed within outward guides affixed to the seating. The weight is brought upon the valve from a low-fixed centre—the centre-pin being jointed to the lever, or fixed thereon by other means, so that there be the requisite play for the pin always to bear on the centre of the spherical Valve. The small weight on the short or fastened end of the lever, is merely for the purpose of balancing the long end of the lever, so that when the ball-weight for weighting the valve is off, the valve is entirely free from outward pressure. Where this portion of the arrangement is dispensed with, the weight of the lever as it bears on the valve has to be taken into account, when calculating the weight to be used for weighting the valve, and also the several distances on the lever at which that weight will have to be placed for the various pressures required.

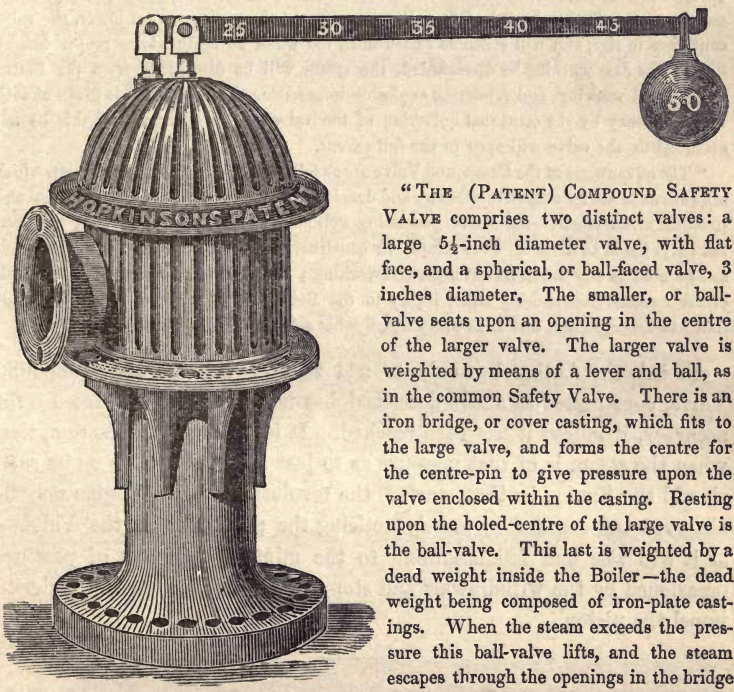
In all cases it is advisable to have the face of the seating of the Safety Valve as narrow as the varying modes of construction will allow. The spherical-faced Valve is best adapted for this and other beneficial purposes: for it is found in practice that the sharp edge of the seating, taken off only by grinding it and the spherical Valve to a face, results in the greatest accuracy that can be obtained—while this form and mode of construction also ensures the best fitting valve for "bottling up" the steam when it is not required to escape.

The Valve shown in the foregoing illustration is not adduced and recommended as one perfect in every particular; but it is believed to be as good a valve as can be made simply as a Lever Valve—securing the greatest accuracy of which this form of construction is capable—one providing for the discharge of steam better than any other mere Lever Valve yet introduced.

In connection with this subject of Safety Valves, the Author would not be doing his duty to those for whom his work is intended, were he, from any feeling of mock-modesty, to refrain from describing the construction and the advantages of what is now very well known as "HOPKINSON'S (PATENT) COMPOUND SAFETY VALVE"—as that Valve possesses important features not to be found in connection with any other valve: and as it provides against that prolific source of Boiler explosions, deficiency of water, as well as for the copious discharge of steam at over-pressure, under the ordinary conditions of working. When the facts are stated, that this Compound Valve has been applied to upwards of four thousand Boilers—and that in no single instance has a Boiler with this Valve attached, exploded or suffered injury, either from over pressure or deficiency of water—while most numerous are the instances where Boilers have been *saved* by the simple, but certain, action

of the instrument, under circumstances which, with the ordinary valve, would inevitably have resulted in explosion,—the Author feels that he may fairly claim to be exempt from the charge of "puffing his own wares" in giving the following description of a construction which has already effected much good, and which, as experience warrants him in saying, is the most effectual *Safety* Valve ever yet introduced into Steam Engineering.

The description of the Compound Valve which follows, formed part of a Paper read before the British Association, at the Leeds Meeting in 1858 :—



"The (Patent) Compound Safety Valve comprises two distinct valves: a large 5½-inch diameter valve, with flat face, and a spherical, or ball-faced valve, 3 inches diameter, The smaller, or ball-valve seats upon an opening in the centre of the larger valve. The larger valve is weighted by means of a lever and ball, as in the common Safety Valve. There is an iron bridge, or cover casting, which fits to the large valve, and forms the centre for the centre-pin to give pressure upon the valve enclosed within the casing. Resting upon the holed-centre of the large valve is the ball-valve. This last is weighted by a dead weight inside the Boiler—the dead weight being composed of iron-plate castings. When the steam exceeds the pressure this ball-valve lifts, and the steam escapes through the openings in the bridge casting into the dome, or shell-casing, and out into the atmosphere. As soon as the ball-valve lifts from *its* seat, the large flat valve also lifts from *its* seat; thus *a double means of discharge* is given to the excess of steam. This feature is of importance, inasmuch as the whole construction forms a valve possessing an opening, or discharging area, equal to an ordinary Safety Valve 8¼ inches diameter.

"The Compound Valve cannot be weighted beyond its working pressure whilst the Boiler is at work. Should an attempt be made to over-weight the outside lever, or even should a man press upon it with all his force, it would be useless. So long as the ball-valve is there, properly weighted inside the Boiler, all is right. Should the ball-valve be over-weighted intentionally, whilst the Boiler is standing for cleaning, it may instantly be detected on getting up the steam.

"Turning to the next feature, we come to an improved arrangement for deficiency of water. There is a lever suspended in the Boiler. The rod which bears the dead weight for the ball-valve passes through a large hole in this suspended lever. On this rod is fixed a collar, arranged so as to allow the lugs of the lever to come in contact with it. One end of the lever, or beam, suspended in the Boiler, bears a large float; and at the opposite end there is a balance-weight, to counteract the buoyancy of the float when immersed in the water. The smaller weight is also to keep the tip of the lever up against the underside of the top of the Boiler. The float on the other end, or long arm of the lever, is immersed in the water to such a depth as is fixed for extreme "low-water mark." Should the water begin to leave the float, the specific gravity of the float will be brought upon the long end of the lever. This lever, it will be remembered, is hung to the Boiler, and works on a centre. By the depression of the long end, the lugs of the short end are brought into contact with the collar on the rod attached to the central, or spherical, valve, and that valve is thereby raised from its seat. Should the water still get lower, the valve continues to rise, and will continue raised until the water be again at its proper height, Should the first warning be disregarded, the steam will be discharged from the Boiler, stopping all working, and rendering explosion impossible. Timely notice is given of such first deficiency by the continual quivering of the valve on its seat; and if this be not attended to, the valve will open to the full extent.

"The advantages of the Compound Valve are as follow:—Its combination of parts, which are such as to act for excessive pressure and deficiency of water; its general mechanical and practical arrangement—the Valve possessing neither spindles, guides, rubbing surfaces, nor parts liable to adhere. It is simple in construction, and certain in action, while it can be used as any other valve for general working; it prevents the careless, the ignorant, or the wanton, from causing either injury to the Boiler, or Boiler explosions; it is not liable to derangement, and is in every detail what a Safety Valve ought to be."

To this the Author has only to add that he believes the Compound Valve, constructed as above described, has not hitherto been exceeded for accuracy, if indeed it has been reached. It is so sensitive in action, that when the steam is of that pressure as to just affect the Valve on its seat, should the Engine be then started, the revolutions of the Engine may be observed and counted by merely noticing the pulsations of the Valve—as it will rise and fall according to the minute variations of pressure occasioned by the withdrawals and stoppages of steam from the Boiler to impel the piston.

RULE TO ASCERTAIN AT WHAT PRESSURE A SAFETY VALVE IS WEIGHTED.

First ascertain the length, in inches, of the fulcrum, and the length, in inches, of the lever, from its attachment to the place where the weight is hung. Then ascertain the weight, in pounds, of the ball-weight.

Multiply the length of lever by the weight of the ball-weight. Then multiply the area of the Valve* by the distance of the fulcrum from the attached end of the lever. Then take the product of the former, and divide by the latter. The quotient is the pressure for which the Valve is weighted in pounds per square inch.

* The area of any Valve may be found on reference to the "Table for Safety Valves, Cylinders, Air Pumps, &c.," in the Appendix.

EXAMPLE.

42 lbs, weight of ball.	10 inches, area of Valve.
50 inches, length of lever.	3 „ length of fulcrum.
2100	30

30) 2100 (70lbs per square inch.
210 ·

This illustration is from the Valve shown by the engraving on page 28, which has the respective measurements and weights figured thereon.

The introduction of the above simple method of calculation is not for the purpose of superseding any readier method, or those usually adopted by the mathematician, and the skilled and practical Engineer. It is intended for those who have not any other means of arriving at the required result.

PLAN AND DIMENSIONS OF A NOMINAL FORTY-HORSE POWER DOUBLE FLUE FIRE-BOX BOILER.

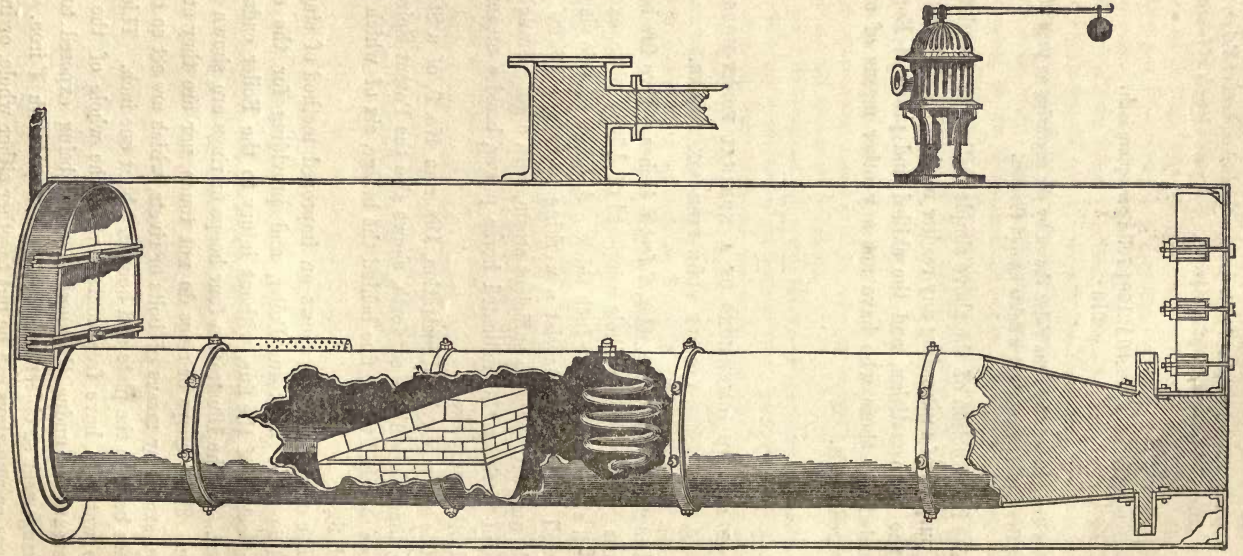
Length, 30 feet; diameter, 7 feet 6 inches. Two fire-boxes and flues, 3 feet diameter. The whole composed of ½ inch plate, except the ends, which should be ⅝ of an inch thick. A Boiler of this size and strength is well calculated to resist a working pressure of 60lbs to the square inch, and will generate sufficient steam, with a good draught, to drive an Engine working 150 indicated horse power, besides steam for warming and other purposes.

The accompanying Illustration, Diagram No. 9, of a Steam Boiler, of the dimensions above set forth, shows also the Patent Spiral Circulating Pipes attached to the flue behind the bridge, six of which are placed in each flue.

The engraving also shows an improved method of staying the flues and ends of a Steam Boiler, and providing for the expansion and contraction of the flue, without injury to the Boiler ends or the angle irons. In the Illustration four hoops or rings are shown encircling the flue. These hoops or rings do not touch, nor are they attached to the flue, except by means of bolts or rivets, which are set so that there is a space betwixt the plate and hoop of about one inch. This space allows the water to have free contact with the whole of the surfaces, and prevents an undue thickness of metal being exposed to the fire—an arrangement so objectionable in flues stayed with T iron. The improved hoops or ring-stays can be put together either whole, or in segments.

Diagram No. 9.

IMPROVED STEAM BOILER.



The staying of the ends is accomplished by riveting a plate on the inside of the end plate of the shell, that plate having slits or spaces for cross plates or bars of such thickness and width as may be deemed of sufficient strength to bear the pressure brought upon the ends of the Boiler. Bolts or rivets proceed through the end of the Boiler, and are drawn up against a collar on the edge of the plates or bars across the Boiler ends. These prevent the Boiler ends from buckling, or getting out of form.

An expansion joint is also shown in the back part of the flue, provided to allow for the expansion and contraction of the flue—an action which in the ordinary construction is very injurious to Boilers, from the sudden heating or cooling, and the various changes in pressure. There is a hoop, to which the sides or copper flanches are affixed, which flanches open or compress as required. The bridge, as shown with an inclined surface, is so formed that the flame and gases may have a free and unobstructed passage into the flue. The feed-pipe is also shown extending some distance into the Boiler, and is perforated with holes, to distribute the water near the surface.

The (Patent) Compound Safety Valve is also shown in elevation on the Boiler. The raised manhole, with branch steam pipe, answers the purpose of a steam chest.

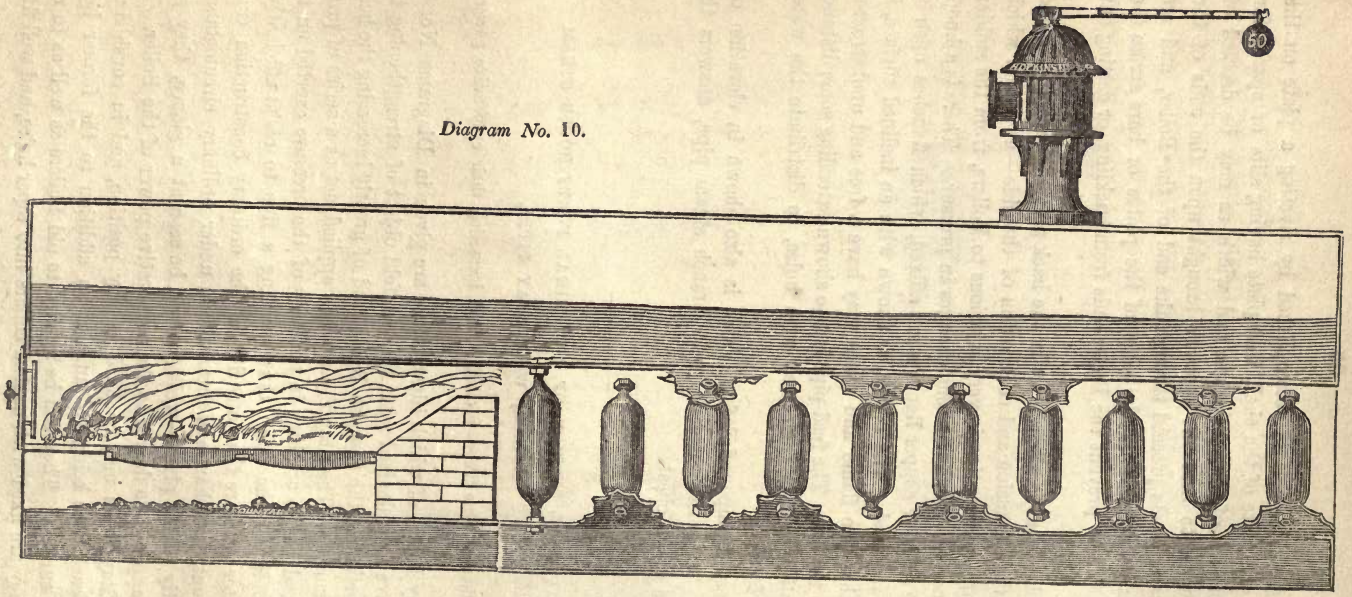
LONGITUDINAL SECTION OF A NOMINAL FORTY-HORSE STEAM BOILER, WITH STAY PIPES,

For strengthening Flue Tubes of Boilers, and increasing their evaporative power.

THE Stay Pipes, of which illustrations are given in Diagrams No. 10 and 11, have been devised with the two-fold object of strengthening the weakest portion of the Cornish Boiler, and of greatly increasing the heat-absorbing surface. The Stay Pipes, when applied, act as a series of props or stays, against the crushing-in tendency of the pressure exerted on the outer diameter of the flue : thus enabling a flue to resist efficiently a much greater pressure than any flue of the ordinary construction could bear, without that change of form which, under ordinary circumstances, is constantly taking place—while, as will be seen at a glance, they add in a very appreciable degree to the evaporative power of the Boiler.

These Stay Pipes may be fixed in any position, and in considerable number—each tube being so much of an addition to the former heat-absorbing surface. They can be applied to old Boilers as well as to new ones. They are fixed with conical collars into taper holes, and well fitted

Diagram No. 10.

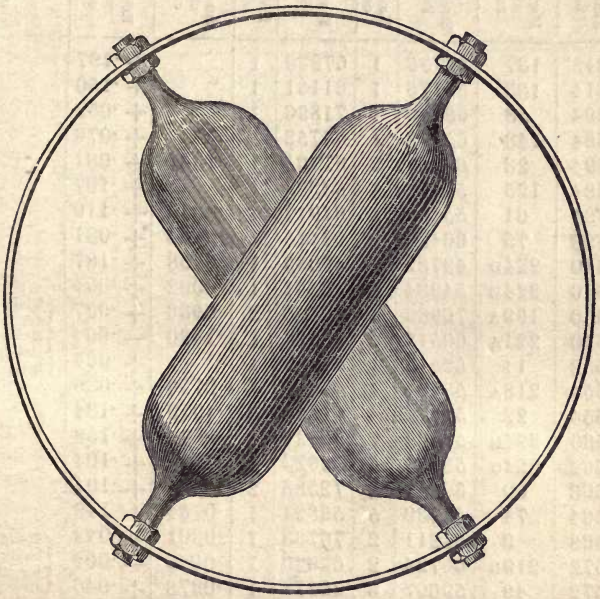


*** This Illustration is in section: and the reader is to *suppose* that the one end of the Stay Tubes, which APPEARS to be unattached, is fixed to the Flue Tube, in the same manner as the other end, and as shown by the enlarged Illustration, Diagram No. 11.

with screws and nuts on the outer diameter of the flue, so that the latter is kept closely pressed up to the pipes. The pipes are made of cast iron, about $\frac{3}{4}$ of an inch thick. When fixed, the whole flue and pipes or props, together, are framed into one compact mass, capable of resisting any pressure that the outer shell of the Boiler will sustain.

Another advantage arising from the application of the Stay Pipes, is, that *circulation* of the water from the space underneath the flue is thereby secured. The pipes take in their supply from the bottom, and discharge the highly-heated water at the top of the flue—thus tending to keep an even temperature in the Boiler, and to prevent that uneven expansion which in the ordinary Boiler is known to be very destructive.

Diagram No. 11.



SECTION OF FLUE OF A STEAM BOILER,

With Cast Iron Pipes with Wrought Iron Ends, Conical Collars, and Nuts.

In the preceding pages hints and suggestions have been put forth, as briefly as was consistent with the important subject in hand. At page 12, on the strength of iron at different temperatures, reference is made to the maximum strength of iron, when heated. The following Table, taken from experiments conducted by the Franklin Institute, in America, will be found worthy of consideration.

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TABLE:

SHEWING THE INCREASE AND DECREASE OF THE STRENGTH OF IRON AT VARIOUS

Comparative view of the influence of High Temperatures on the strength of Iron, as exhibited by 73 experiments on 47 different specimens of that metal, at 46 different temperatures from*

No. of the comparison.	Temperature observed at the moment of fracture.	Mark of the Bar on which the trial was made.	Strength at ordinary temperatures.	No of experiments at ordinary temperatures.	Strength at the temperature observed.	No of experiments at high temperatures.	Amount of variation from uniformity in the cold experiments.	Effects of the heat expressed in parts of the original strength.	REMARKS.
1	212°	137	56736	1	67939	1		+ ·197	
2	214	133	53176	1	61161	1		+ ·150	
3	394	58	68356	1	71896	1		+ ·052	
4	394	148	65143	1	69752	1		+ ·070	
5	394	23	62646	2	67765	1	·1041	+ ·081	
6	394	125	57182	1	63322	1		+ ·107	
7	394	61	55297	5	61917	1	·2026	+ ·119	
8	396	75	60433	3	62415	1	·0444	+ ·031	
9	440	224D	49782	4	59085	1	·0908	+ ·187	
10	520	224B	54934	4	58451	1	·0992	+ ·064	
11	550	199A	76986	4	79846	2	·0936	+ ·037	The standard for the original strength may possibly be a little too high.
12	550	221A	60518	4	60322	1	·1680	— ·004	
13	552	14	52542	1	55932	1		+ ·064	
14	554	218A	58124	4	60412	1	·0730	+ ·039	
15	554	22	54372	4	61680	3	·1919	+ ·134	
16	560	224E	50528	7	58824	1	·0605	+ ·158	
17	562	224C	53385	5	59623	1	·1919	+ ·104	
18	563	60	60907	4	72588	2	·0460	+ ·191	
19	564	74	51030	5	58824	1	·0764	+ ·142	
20	568	9	67211	2	76763	1	·0601	+ ·042	Standard probably too high for the mean strength.
21	572	219B	66724	2	66620	1	·0325	— ·002	
22	572	49	59607	3	62278	1	·0878	+ ·045	
23	572	222B	56165	4	60117	2	·1550	+ ·070	
24	573	10	64511	1	67503	3		+ ·046	
25	574	231	76071	5	65387	1	·1373	+ ·014	
26	575	220A	54263	4	60988	1	·0280	+ ·124	
27	575	62	58376	3	70081	3	·0262	+ ·200	
28	575	207	51924	5	63825	3	·1225	+ ·229	
29	576	221B	59234	5	66065	1	·1190	+ ·115	
30	576	223B	43386	6	50068	1	·0760	+ ·154	

* Showing that Iron Steam Boilers become stronger as the temperature increases, up to about 600°, beyond that temperature it becomes weaker. Copper decreases in strength from 56° upwards.

TEMPERATURES, FROM TESTS BY THE COMMITTEE OF THE FRANKLIN INSTITUTE.

212° to 1317° Fah., compared with the strength of each bar when tried at ordinary temperatures : the whole number of experiments at the latter being 163.

No. of the comparison.	Temperature observed at the moment of fracture.	Mark of the bar on which the trial was made.	Strength at ordinary temperatures.	No of exp. at ord. temp.	Strength at the temperature observed.	No. of exp. at high temp.	Amount of variation from uniformity in the cold experiments.	Effects of the heat expressed in parts of the original strength.	REMARKS.
31	577°	164	58769	5	66929	2	·1214	+·139	
32	578	224A	52406	5	59197	1	·0565	+·129	
33	578	223A	45757	5	53465	1	.0896	+·168	
34	580	86	62156	3	77163	2	·0986	+·052	
35	590	220B	59459	5	62966	1	·0680	+·058	
36	598	90	50316	5	57310	2	·2401	+·138	
37	630	219A	59530	4	60010	1	·1440	+·008	
38	636	16	53543	1	50039	1	·1563	—·067	This experiment was on a part probably defective.
39	662	150	59307	5	58181	1	·0644	—·019	
40	722	152	57133	3	54441	1	·0507	—·047	
41	732	14	52542	1	53378	1	·1310	+·016	
42	734	150	59397	1	57903	1	·0644	—·026	
43	766	16	56891	1	54819	1	·1563	—·037	
44	770	149	56825	2	54781	1	·0234	—·036	
45	824 and 814	214	59219	1	55892	1	·0413	—·073	
46	825	149	56825	2	56644	1	·0234	—·029	
47	932	214	59219	1	45531	1	·0413	—·240	
48	947	232	58341	2	42401	1	·0446	—·273	
49	1022	214	59219	2	37410	1	·0413	—·369	
50	1037	152	58992	1	37764	1	·0507	—·360	
51	1097	227	53426	6	27604	1	·0330	—·483	
52	1111	227	53426	6	27602	1	·0330	—·483	
53	1142	226	54758	2	18672	1	·1147	—·659	The metal was decidedly defective at the point where this fracture was made—flaws visible.
54	1155	227	53426	6	21967	1	·0330	—·589	
55	1159	229	55774	3	25620	1	·1102	—·538	The 8th experiment on this bar being taken as the standard, would exhibit the effect—·550,
56	1187	227	53426	6	21910	1	·0330	—·589	
57	1235	226	54758	2	21298	1	·1147	—·611	
58	1245	226	54758	2	20703	1	·1147	—·622	
59	1317	226	54758	2	18913	1	·1147	—·654	
			Mean—57525						

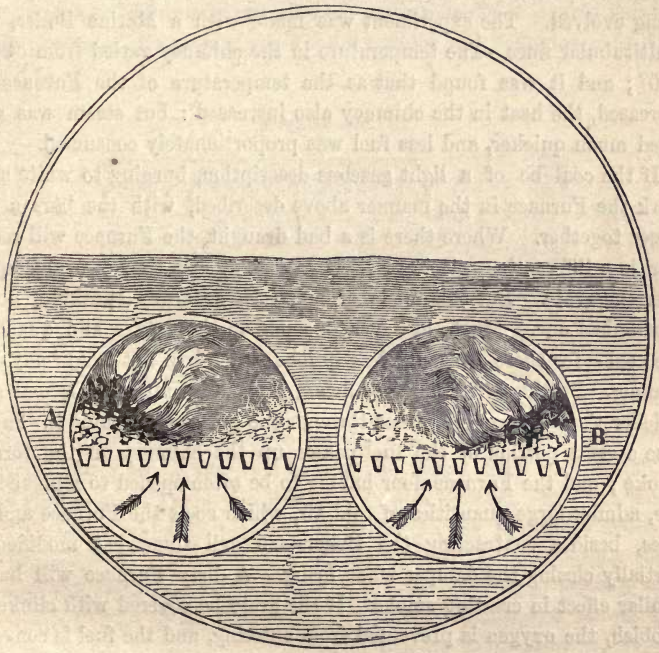
CHAPTER II.

THE FURNACE AND ITS ADJUNCTS.

After seeing that all the fittings of the Boiler are in the best possible order, and the Boiler in good working condition, turn attention to the Furnace. There is more required here than the simple process of feeding the fire with fuel. In the first place, the nature of the coal should be ascertained—whether or no it be of a coking description. If it be, the grate bars will require to be more open than for coal of a light and gaseous nature. Adjust the grate-surface to the heating or absorbing surface of the Boiler. This will greatly depend upon the quality of the fuel and the draught, and the quantity of steam required. If the draught be good, work a thick fire; but do not break the coal except it cannot be got in at the Furnace door, taking care to feed the Furnace on one side, not covering more than one half the grate at a time. When that is sufficiently coked, feed the other side, putting plenty on at a time, leaving the middle of the Furnace much lighter and thinner of fuel than the sides, and keeping the grate bars well open. This mode of stoking—placing the coal on one side at a time—will prevent the formation of a great portion of the smoke which would otherwise result, and also produce a more steady heat. The coal so placed will partially damp that side of the Furnace on which it is placed: *therefore the necessity of stoking the Furnace when the steam is up.* From this method of firing, the gas generated will be given out slowly. The greatest quantity of air will pass through that portion of the grate where the fuel is most consumed, and where the coal has not been made small by breaking, leaving the interstices wide; and as the oxygen of the air will generally be in sufficient quantity, if this mode of firing be adopted, to unite with the gas as it is extracted from the coal, a continuous flame will be kept up, and smoke prevented. When one side of the Furnace so fired is sufficiently coked, raise the burning fuel gently with the poker, but do not break it into pieces. At the next firing, place the coal on the other side of the Furnace, and similar results will follow. Replenish first one side, and then the other: and continue to do so in the working of the Furnace. Keep the Furnace door open no longer than is absolutely necessary, and thus prevent the admission of large volumes of cold air to cool the Boiler and flues. Place your coal, before firing, near to the Furnace, that there

may be no loss of time in charging the fire. Cold air coming in contact with the Boiler lets down the temperature, and does harm. To ensure that the coals be sufficiently near, and that the Stoker cannot have them too far from the Furnace doors, it is best to erect a barrier in front of the Boiler, at about six feet distance, with an opening at the bottom. The coals behind this barrier will have to be up to the opening at the bottom. This mode will enable the Stoker to charge his Furnace with fuel without moving from the front. He will thereby take less time, and be able to close the door earlier, than if he followed the ordinary modes of stoking.

Diagram No. 12.



If the Engineer is working a Double Fire-box Boiler, let him fire each Furnace alternately, in the manner above described, and as illustrated by the accompanying engraving, Diagram No. 12, where A and B represent the sides of the fires last stoked, with the gas given out from the new fuel, mixing with the air which passes in the greatest quantity through the thin portion of the fire, as indicated by the arrows : and with that also which passes through the apertures in the furnace doors, or through

any special provision that may be made. Being thus mixed with air at a high temperature, the gases ignite, and comparatively thorough combustion is secured, preventing smoke and saving fuel. This mode of firing is applicable to most Furnaces, whether single or double fire-box, or with the fire wholly beneath the Boiler. The hotter the fire, the more steam will there be generated with the same quantity of fuel; and though a greater amount of heat may pass up the chimney, there will be a corresponding saving of fuel, in proportion to the increase of temperature.

There are various qualities of coal, and various power of draughts. A good quality of coal, with a good draught, will evaporate 7lbs of water for each 1lb of coal, in a Double Fire-box Boiler; and other qualities not so good, from 5lbs to 7lbs. In a trial at Newcastle-upon-Tyne, the Author evaporated 11.70lbs of water with 1lb of coal, without any smoke being evolved. The experiment was made with a Marine Boiler, with multitubular flues. The temperature in the chimney varied from 500° to 650°; and it was found that as the temperature of the Furnace was increased, the heat in the chimney also increased: but steam was generated much quicker, and less fuel was proportionately consumed.

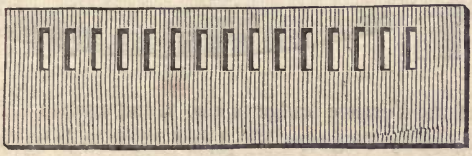
If the coal be of a light gaseous description, burning to white ashes, work the Furnace in the manner above described, with the bars a little closer together. Where there is a bad draught, the Furnace will require working differently—placing a little coal on at each time of firing, equally over the grate. But this mode of firing is, generally speaking, not an economical one. Much, however, depends on the nature and quality of the coal—for there are some descriptions which will not fire in any other manner. By this latter mode of firing, the gas is extracted from the fuel quicker than the oxygen passes through the grate to consume it. In that case a great portion of the fuel passes up the chimney in the form of smoke; and the Furnace door having to be often opened to replenish the fire, admits large quantities of cold air, which cools the Furnace and the flues, besides contracting the Boiler—an evil somewhat modified by partially closing the damper when firing. A dirty Furnace will have a similar effect in creating smoke. If the grate be covered with clinkers or rubbish, the oxygen is prevented from entering, and the fuel is converted into smoke. In fact, this is one of the most prolific sources of the "smoke nuisance."

By all means avoid having a dirty ashpit. A pit nearly full of ashes is a sure sign of bad management. It is as necessary to keep the ash-pit of a Furnace clean and cool, and the air as dense as possible, as it is to feed the fire with fuel. If the ash-pit be hot, the heat expands the air, and the Furnace will require *greater quantities* to pass for the amount of oxygen which would be supplied by less quantities of cold air. These

greater quantities impair the draught. When convenient, use water for the bottom of the ashpit, allowing it to remain to quench the ashes as they fall from the Furnace. The evaporation will tend to keep the grate cool. Have, if possible, some water near the Furnace, so that when cleansing the fire you can cool the slag, that you may remove it early. These things, properly attended to, will cause the Furnace to wear much longer, and also save fuel. There will likewise be less labour to produce more steam in the same time than a slovenly mode of stoking would produce.

A great body of fire will evaporate more water with a less proportion of fuel than a small and thin fire. The greater the intensity of the fire, the more will be the steam generated with the same amount of fuel. Where there are a number of Boilers, it is important that the duty of stoking should be properly attended to; and as smoke is a great nuisance, easily prevented, its prevention is a duty which every Engineer ought to attend to.

Diagram No. 13.



With regard to the consumption of smoke, it may be observed that the heat of one fire coming into contact with the gases of another fire behind the bridge, or in what is called the "combustion chamber," does not consume the smoke. Smoke cannot be consumed after it has left the Furnace, unless air be admitted to mix and ignite with it, and the gas must also be of sufficient temperature to cause ignition. The best part of the Furnace in which to admit air to ignite the gas, is near to where the gas is generated. If additional air be required to that which passes through the grate and Furnace-door, it is best admitted at the bottom of the Furnace-door, or through the dead-plate, as illustrated by Diagram No. 13, which represents a dead-plate pierced with apertures for the admission of air through and amongst the coking coal. This method of admitting air has been much resorted to since the first edition of the work in which it was described and made public, first appeared.* This method is recommended by the "Lancashire Association for the Prevention of Boiler explosions;" and the Author, having had more than twenty years' experience with all and every kind of smoke-prevention apparatus, is able

* "The Steam Engine Explained by the use of the Indicator," by Joseph Hopkinson.

to say that he never found anything to answer so effectually as the mode of firing before described and illustrated, in combination with this mode of admitting air at the Furnace-door or through the dead-plate, when the requisite amount cannot be got through the ordinary grate.

All Furnace-doors should have a number of half-inch holes cast or drilled through, independent of all other contrivances. The air passing through these holes into the Furnace keeps the doors cool, and assists combustion.

The annexed Diagram, No. 14, is a representation of a grate bar, and bearers. The bar C shows one end hooked on to the left hand bearer B. The other end of the bar slopes, and rests upon the other or right-hand bearer B. As the bar expands or contracts, the sloping end, being loose, can move without straining, or buckling the bar. With this free action, the grate will last much longer than ordinarily, and the openings can be kept more even.

Diagram No. 14.

The form of the Furnace bridge is also of importance. If it be made inclined, as shown by Diagrams No. 9 and 10, it will last much longer, and the heat will be more evenly distributed in the Furnace, to the increase of the evaporating power. When the Furnace is cleansed, the hot fire can be pushed up the incline, while the clinkers are removed : thus enabling the stoker to clean the whole of the grate at one time. And, besides this, the reflected heat of the hot brick-work will impinge against the top part of the fire-box flue, or the bottom of the Boiler, if of another construction ; thus keeping the Furnace-door much cooler than when the bridge is built perpendicularly—the reflected heat in the latter case impinging on the front, causing that part to be much hotter than where the bridge is inclined, as here described.

The opening between the grate-bars is an important point to be attended to. If these are not sufficiently wide, the Furnace becomes a retort for the destructive distillation of coal, the gases passing off in the form of smoke for want of a sufficient quantity of air to consume them as they are generated. Smoke is often produced from the bars being too close together ; and it is false economy to suppose that fuel is saved by having the apertures between the grate-bars too small. A proper thickness of the bars, also, is a requisite in practice. These have been found to answer best when about one-half or three-quarters of an inch thick.

Attention to the foregoing rules, viz :—careful firing, clean grates, wetting the small coal, placing plenty on at a time, firing alternately at the sides, a clean ash-pit, and, above all, a good draught, will, for all practical purposes, prevent the formation of smoke. That attention will also prevent waste of fuel, save time and labour, and reduce wear and tear. Of course, under different circumstances, modifications will be required, varying accordingly; but by the adoption of the principles herein laid down, the "smoke nuisance" would soon cease to be a cause of complaint.

The following Table of the evaporative powers of various descriptions of coal when burned under Boilers, is given by Mr. Wicksteed :—

TABLE OF THE COMPARATIVE EVAPORATIVE POWERS OF DIFFERENT KINDS OF COAL.

No.	Description of Coal.	Water evaporated per lb of Coals.	Comparative Cost per Ton in London.
		lbs.	*s.* *d.*
1	The best Welsh	9·403	17 11
2	Anthracite	9·014	17 0
3	The best small Newcastle	8·524	16 1
4	Average small Newcastle	8·074	15 2¾
5	Average Welsh	8·045	15 2¼
6	Coke from gas-works	7·908	14 11
7	Coke and Newcastle, small ½ and ½	7·897	14 10¾
8	Welsh and Newcastle, mixed ½ and ½ ...	7·865	14 10
9	Derbyshire and small Newcastle, ½ and ½ ...	7·710	14 6½
10	Average large Newcastle	7·658	14 5½
11	Derbyshire	6·772	12 9¼
12	Blythe Main, Northumberland	6·600	12 5½

The Author evaporated 11·70lbs of water in a Marine Boiler, with 1lb of the best Newcastle coal, when contesting for the £500 prize offered by the Newcastle Coal Owners' Association some years ago, for the best smoke preventive; and he further offered to evaporate 12·70lbs of water with 1lb of coal, provided the Furnace were altered as he might direct.

With good Lancashire or Yorkshire coal, and a Double Fire-box Boiler, new, and a moderate draught, 7lbs of water can be evaporated with 1lb of Coal. When the Boiler has been some years at work, the evaporation will vary from 5lbs to 7lbs—the work greatly depending upon the state of the flues and the cleanliness of the Boiler-plates, inside and outside. Inferior coal will not evaporate more than from 4lbs to 5lbs of water with 1lb of coal. The strength of the draught has a good deal to do with the economy of fuel: the stronger the draught, and the greater the evaporative power of the coal. The greater the intensity of the fire, the more completely are the gases consumed.

CHAPTER III.

THE ENGINE.

THE Engine itself requires but little attention when in good order, except the ordinary routine of packing, cleaning, and oiling the working parts, and occasionally adjusting the cotters, which on no account ought to be neglected.

Indicate the Engine every day. Perform the operation when the load is on. Work up the diagram, and place it in a book, with the date, for reference at any future time. This mode will denote the difference of power required under different circumstances, and also make known any defective working, whenever any part of the Engine gets out of order, or whenever any shafting or machinery is taking more power at one time than another.

It will not be necessary to work up the diagram each time. When the Indicated Horse-power has been once ascertained, the following rule will be found to be correct enough for all practical purposes, and much more ready than working the diagram each time thoroughly out.

EXAMPLE:

Say the Diagram represents 99 horse power, when the friction of the Engine and shafting is deducted.

Divide by the average pressure,
say...12lbs) 99 (8¼lbs horse power for each pound pressure per
96 square inch upon the piston.

3 remains ; this being ¼ of 12, it makes the total to be 8¼ horse power.

If a diagram be taken from the same Engine, with less, or more, average pressure, multiply the average pressure upon the piston by 8·25, to ascertain the horse power the Engine is then exerting.

EXAMPLE:

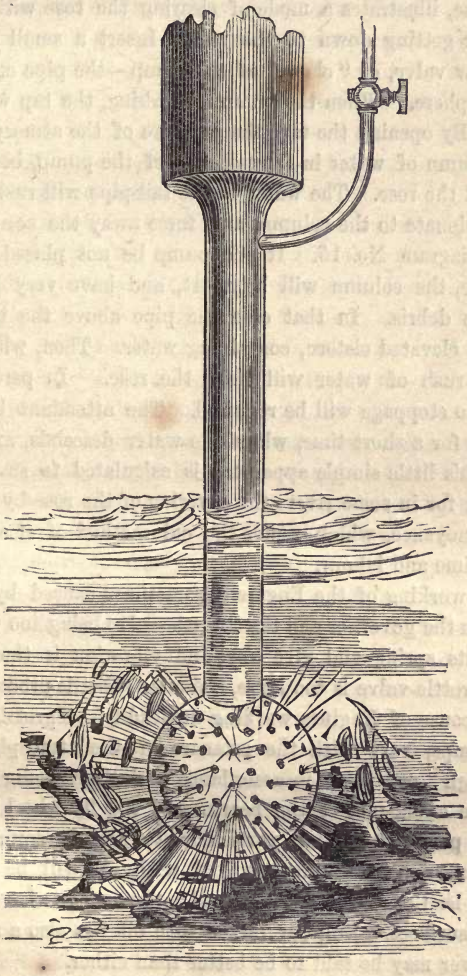
15lbs the pressure upon the piston.
8·25 the number of horse power for each pound pressure upon the piston.

75
30
120

123·75 horse power.

The horse power being 123$\frac{3}{4}$lbs. It matters not whether the horse-power be required independent of the shafting and Engine, the calculations are made the same. Each Engine indicated will require the first diagram taken to be figured up, and worked out in the ordinary way, hereinafter described, to ascertain the horse power the Engine is turning.

Diagram No. 15.



Use a thermometer to test the temperature of the condensing water, which ought not to exceed 120 degrees of Fahrenheit. Work as much below that temperature as is consistent with the supply of water to the

Boiler, and the quantity the air-pump will discharge—keeping the delivering-valve closed as long as possible. If the water in the air-pump thump and plunge, a small air-pipe inserted in the pump lid will often prove to be a remedy.

Should the rose of the pump become choked, or stopped with dirt or leaves, as is often the case when water is drawn from rivers, pools, dams, streams, and even wells, the foregoing sketch of a pump-head, tail-pipe, and rose, illustrates a mode of clearing the rose without stopping the pump, or getting down to the rose. Insert a small pipe and tap under the low valve, or "clack," of the pump—the pipe end being open to the atmosphere. When the pump is working, the tap will be closed, of course. By opening the tap, the pressure of the atmosphere will act upon the column of water in the tail-pipe of the pump, betwixt the low "clack" and the rose. The water in the tail-pipe will rush back with a force proportionate to the column, and force away the accumulations, as shown by Diagram No. 15. If the pump be not placed much higher than the rose, the column will be short, and have very little force to drive off the debris. In that case the pipe above the tap should be carried to an elevated cistern, containing water. Then, when the tap is opened, the rush of water will clear the rose. In performing these operations, no stoppage will be required. The attendant has simply to open the tap for a short time, while the water descends, and then close it again. This little simple apparatus is calculated to save much time and trouble; for in some rivers the covering of the rose by refuse matter is a great annoyance, which, under the old method of clearing, involves a waste of time and labour.

Unsteady working of the Engine is sometimes caused by the connections between the governor and the throttle-valve being too weak; in that case the parts spring and give way, and vibration is the consequence. When the throttle-valve is too large, a similar effect is produced; and this is often the cause of Engines working unsteadily. Throttle-valves regulated by pumps, vary with the pressure of the atmosphere; for the water is "high" or "low," in accordance with the varying pressure.

Should the crank-pin, or the bearings of the fly-wheel shaft, or any of the other parts become hot, particular attention is required to prevent their destruction. Lead filings mixed with oil will be found to be useful. The lead coats the bearings, and interposes another body between the rubbing surfaces. Sulphur mixed with oil has also a similar effect; and quicksilver may be said to be better than either.

The following recipe for cooling necks of shafts will be found useful, not only for the crank shaft, but for all other descriptions of shafting—particularly the feet of upright shafting :—

16lbs of Tallow, dissolved in a vessel. 2¼lbs of white Sugar of Lead. When the Tallow is melted, but not boiling, put in the Sugar of Lead, and let it be dissolved. Then put in 3lbs of black Antimony. Keep stirring the whole mass till cold.

It is an axiom that "prevention is better than cure." There would seldom be heating of necks of shafting, were those necks made of a proper length. They should, in all cases, be at least *twice* the length of the diameter of the shaft. The "brasses," or "steps," should be made of good metal, composed of three parts of copper to one part of tin. Good brasses involve more "first cost," but they secure a saving of oil, and also power. More attention than is now usual ought to be paid to the quality of the metal of which "steps," or the bearings of shafting, are made. Above all, be careful to keep dust away from the necks and "brasses" of shafting, and other bearers: for cleanliness in this particular is a great preventive of destruction.

Pay proper attention to all packings, to prevent the escape of steam or water. Such leakages often cause more destruction than ordinary wear and tear. If the injection cock or the condenser be leaky, the water will get into the cylinder when the Engine is standing, in consequence of the partial vacuum; and at starting afterwards, the water will, in all probability, be the means of breaking the beam or some other part. Care should be taken that all taps connected with the cylinder are closed when the Engine is at rest, except a small tap connected to the condenser; and whenever the Engine is stopped, this tap should be opened to destroy the vacuum, or the water may, from some cause, get into the cylinder. At starting the Engine, close the tap. This simple arrangement will be the means of saving much trouble, and probably prevent breaks-down. This tap will also be found useful in stopping the Engine at any required angle of the crank, by admitting air to the condenser, and destroying the vacuum.

Keep the pipes and cylinders clothed with a non-conducting substance, to prevent the escape of caloric from the steam. It will pass away very quickly, if means are not used to retain it—causing a loss of fuel.

Have a vacuum-gauge fixed near to where you pass in the Engine-house, that the quality of the vacuum in the condenser, or the amount of the uncondensed steam, may be easily examined. The vacuum-gauge should be one that shows the pressure of the uncondensed steam left in the cylinder, and the pressure of the atmosphere at the same time. Otherwise it cannot be ascertained by the *Indicator*, when the vacuum varies, whether it be from the pressure of the atmosphere or the deficient vacuum of the Engine. In some states of the weather the pressure of the atmosphere will be under 14lbs to the square inch, and at other times it will be upwards of 15lbs to the square inch. Steam may be 20lbs

above the atmosphere; but when the pressure of the latter is 14lbs, the steam will be 34lbs. But if the pressure of the atmosphere be 15lbs to the square inch, the steam in the Boiler will be 35lbs; and so on in proportion to the varying pressures of the surrounding medium.

Have proper taps fitted to the top and bottom of your cylinder, that you may indicate your Engine with ease. By indicating each end, you will see if your valves are equally set. Both ends can be indicated on one paper. After using the *Indicator*, clean it well: a dirty *Indicator* is an indication of a slovenly Engineer.

WHAT IS THE VACUUM OF A STEAM ENGINE?

It is essential that we define and understand the term "VACUUM," as commonly applied to the Steam Engine—(and unless this be well understood by the Engineer, he cannot clearly understand the Condensing Engine)—before we enter into a description of the diagrams which are hereafter given. The following popular explanation is therefore attempted.

Steam is an invisible fluid. When steam, as it is called, is seen like white smoke, it is not steam, but minute particles of water. Pure steam in a glass will not show at all—but the vessel appears to be filled with air only. One cubic inch of water converted into steam at the atmospheric pressure of 15lbs, the temperature 212°, will expand to 1700 cubic inches of steam. If the temperature be increased, the pressure will be increased also in the ratio of the temperature. Thus, with steam at 251½ degrees, the pressure will be 15lbs above atmospheric pressure; the total pressure, 30lbs to the square inch, and the bulk 883 times greater than the bulk of the water from which the steam was produced. If the total pressure be 60lbs, or 45lbs on the steam gauge, the bulk will be 470 times greater than the water the steam had been produced from. In proportion to the increase of pressure, so is the density.*

The literal meaning of the term "vacuum," is space unoccupied by matter. The cylinder of a Steam Engine filled with steam, though vaporised from a small quantity of water, cannot be said to be void of matter; but condense that steam to its original bulk into water, and withdraw this water from the cylinder, and the space formerly occupied by the steam will be unoccupied. No matter remaining in the cylinder, there is what is termed a "vacuum," or a void space. We have supposed this operation to have taken place under the piston of a Steam Engine, and in that case there is no resistance to be overcome in the descent of

* See the Table hereafter given, shewing the "Temperature of Steam at different pressures."

the piston. The pressure of the atmosphere alone, which is 15lbs to the square inch, or thereabouts, would suffice to force the piston down with a power equal to the degree of vacuum formed, up to the limit stated—15lbs, if the vacuum be perfect. On this principle the first Steam and Atmospheric Engine was constructed: a cylinder with its upper end open to the atmosphere; steam was admitted below the piston to raise it, and this steam being condensed in the cylinder itself by the application of cold water, the pressure of the atmosphere alone caused the downward stroke in the manner above described. If steam be allowed to take the place of the atmosphere, as in WATT's Engine, steam at atmospheric pressure will produce the same effect. 1700 cubic inches of steam, or one cubic inch of water converted into steam at atmospheric pressure, will have a force sufficient to raise a weight of one ton one foot high; two cubic inches of water, two tons; and each ton extra, one additional inch of water converted into steam. One of WATT's first improvements was to attach to the Steam Engine a second vessel, in which to condense the steam. This he called a "condenser." He also introduced other alterations by which the vacuum was much improved, and the steam made to answer two purposes. First, by closing the cylinder with a cover, and admitting the steam between the cover and the piston, and connecting each side of the piston with the second vessel, or condenser—the condenser being supplied with cold water—the steam was admitted at the same time by valves opening and closing at each stroke of the Engine. The steam was thus condensed, and a partial vacuum formed; and thus the power of steam at a pressure above the atmosphere was made available, in addition to the pressure of steam below the atmosphere. By admitting the steam alternately on each side of the piston, after a partial vacuum had been formed in the second vessel, or condenser, and the Engine cylinder, the Engine was thereby made to be double-acting, and its power increased in proportion to the pressure of the steam above the pressure of the atmosphere.

Steam arising from an open vessel—for instance, from the manhole of a Steam Boiler—has a force greater than the pressure of the atmosphere, inasmuch as it has to displace the atmosphere before it can rise above the surface of the water. The resistance of the atmosphere is equal to about 15lbs on the square inch. It varies from 13½lbs to upwards of 15lbs; on the average it is about 14¾lbs to the square inch. 2·037 inches of a column of mercury balances 1lb pressure to the square inch. Therefore, steam enclosed in a Steam Boiler at 5lbs pressure per square inch above the atmosphere, or, in other words, at 5lbs on the steam gauge, is, in reality, a pressure of 20lbs on the square inch, as applied to the piston of a Steam Engine under the conditions above stated—taking the pressure of the atmosphere at 15lbs. If the pressure be less, as it often is, say 14lbs

then the pressure upon the piston would be 19lbs, because the resistance of the atmosphere on the safety-valve and steam-gauge would be less, and the steam in the Boiler also less, in proportion to the reduced pressure of the atmosphere. Hence it arises that an Engine heavily loaded varies in its speed with the varying pressure of the atmosphere. Suppose that the vacuum is not perfect—and in practice it never is so—and that there remains in the cylinder a portion of uncondensed steam, the resistance of which is equal to 3lbs to the square inch, then the steam on the upper side of the piston at 5lbs to the square inch above the pressure of the atmosphere, would act with an effective force of 17lbs upon the square inch : the upper side of the piston having exerted upon it a pressure equal to 20lbs to the square inch, and the under side a pressure, or resistance, equal to 3lbs to the square inch. Under these circumstances, the condenser will have exhausted steam from the cylinder equal to 12lbs to the square inch, commonly termed a 12lbs vacuum ; and uncondensed steam will have been left in the cylinder, having a resisting force equal to 3lbs to the square inch. In proportion to the quantity of steam condensed to the whole, so is the value or available pressure upon the piston. If the uncondensed steam left in the cylinder were equal to 6lbs to the square inch, then, in the other circumstances supposed, the available pressure upon the piston would be only 14lbs to the square inch—a proof that vacuum is not power, as many are led to suppose. All power in the Steam Engine is derived from the pressure of the steam upon the piston. If there be no resistance on the other side of the piston, the whole pressure is available ; when there is resistance, whatever be the amount, it has to be deducted. The available power of steam on the piston is what is left of the whole force when that deduction is made. The term "suction" is often used. There is no such process in nature, or in mechanics ; and the use of the term only tends to confound the practical worker. All power derived from air, steam, or gas, is the result of pressure, or density ; and in proportion to the pressure, so is the power.

If 5lbs more pressure to the square inch be added to the 5lbs before described, the pressure of the steam above the atmosphere will be 10lbs to the square inch, making only 25lbs as the available pressure. Many suppose that by doubling the pressure above the atmosphere, or double the pressure on the steam gauge, they double the power of the steam, and that they also double the power of the Engine. Such is not the case. They have only, in the case last supposed—though the pressure of steam in the Boiler above the atmosphere is doubled—added 5lbs to the 20lbs already available. This only gives 25lbs to the square inch upon the piston of the Engine, in place of 20lbs. The increased power

of the Engine is as 25 is to 20, supposing the non-resistance, or in other words, the vacuum, to be the same. In the practical working of Engines, it is seldom that the full pressure in the Boiler can be brought to bear upon the piston. To ascertain the real pressure operating on the piston at any given time, the *Indicator* has to be resorted to, in the manner hereinafter explained.

These examples have reference only to Condensing Engines. High-pressure, or Non-condensing Engines, are constructed upon a different principle. In them, the power of the Engine is as the pressure of the steam above atmospheric pressure. Steam at 30lbs to the square inch above the atmosphere, that is 30lbs on the steam gauge, applied to the piston of a High-pressure or Non-condensing Engine, will exert a force equal to the pressure in the Boiler above the atmosphere, providing there be sufficient room in the passages betwixt the cylinder and the Boiler, so that obstructions in the steam course do not reduce the pressure before entering the cylinder—the other side of the piston being open to the atmosphere, and the steam only having to overcome the atmospheric pressure in its escape from the cylinder. 15lbs from the total pressure of 45lbs is lost, provided the steam has been expanded in the cylinder to its full limit, which is not often the case in practice. If not expanded, the loss will be greater ; it will be in proportion to the pressure of the steam on the piston above the atmosphere at the termination of the stroke. If we double the pressure in the case just supposed, and bring the whole to bear upon the piston, and expand the steam to atmospheric pressure, the power of the Engine will not be doubled, but will be as 52 is to 31; because the pressure of the atmosphere added to 60 makes 75, not twice 45, which would be 90. Where a partial vacuum is formed, as in the Condensing Engine, steam at 30lbs to the square inch above the atmospheric pressure would press with a force equal to 42lbs per square inch, supposing the resistance of the uncondensed steam to be only equal to 3lbs to the square inch. As before observed, the one side of a piston of a High-pressure Engine is open to the atmosphere through the exhaust pipe, when the steam is exerting its force on the other side ; and as the resistance of the atmosphere is 15lbs to the square inch, it follows that the power of the steam is as its own pressure above the atmosphere : or in other words, the pressure above the atmosphere is the available power obtained in the High-pressure or Non-condensing Engine, when the full pressure in the Boiler is brought upon the piston.

The steam upon the piston of some Condensing Engines, is, at one portion of its stroke, below the atmospheric pressure. The pressure of the steam upon the piston at the commencement of the stroke or descent of the piston, is for one-seventh the length of the cylinder, equal to 32lbs to the square

inch, or 17 lbs to the square inch above the pressure of the atmosphere. The valve is then closed, and the communication with the Boiler cut off—and the steam in the cylinder is expanded for the remainder of the stroke, decreasing as the piston approaches nearer and nearer to the end of the cylinder. Suppose the grease tap in the cylinder to remain open during the whole length of the stroke, the steam will rush out in proportion to its own pressure above the atmosphere, until the pressure is equalised. As the piston descends, the pressure of steam is reduced, by expansion, until it gets below the pressure of the atmosphere; and then the atmosphere will rush into the cylinder. At the same time the cylinder will be full of steam. After crossing the atmospheric line, the steam is not equal to the resistance, or the power of the surrounding medium; therefore, at one portion of the descent of the piston the steam will rush out, displacing the air for a certain distance of the stroke from the top of the cylinder; and at the other portion of the stroke, or of the piston's descent, the air will rush into the cylinder, when the steam is below the pressure of the atmosphere, and will exert a force upon the piston equal to the difference in pressure between the steam and the air, because the pressure of the steam in the cylinder has been reduced by expansion below the pressure of the atmosphere; but when steam below the pressure of the atmosphere is admitted into the cylinder at the commencement of the stroke, the air will rush into the cylinder at the time the steam from the Boiler is admitted, if the grease-tap be kept open from the commencement of the stroke to the end; thus showing the Engine to be working with steam at a less pressure than steam from an open vessel; or in other words, steam below the pressure of the atmosphere. Were the openings sufficiently large to admit a sufficient quantity of air, no steam could enter the cylinder against the superior pressure of the atmosphere. If the steam in the Boiler were below the pressure of the atmosphere, the Boiler would soon be filled with air.

When steam at a pressure above the atmosphere is admitted into the cylinder, and kept up to the end of the stroke, the steam would rush out of the grease-tap, were it open the whole length of the stroke—because the steam in the cylinder has not been reduced by expansion, but has to be condensed in the condenser by an extra quantity of water; thus giving the air-pump more work to do, and losing a quantity of steam in proportion to the pressure. If the steam be reduced to the lowest practical working pressure by expansion, the most has been made of it; but if not expanded to its full limit, the loss will be in proportion to the amount of pressure left in the cylinder previous to condensation—or the exhaustion into the atmosphere, if a High-pressure Engine.

In a Steam Engine not heavily loaded, working with steam below the

pressure of the atmosphere from the Boiler and in the cylinder, were the Safety-valve lifted from its seat, air would rush into the Boiler, until the pressure became equal to the pressure of the atmosphere. Thus, air and steam would rush into the cylinder of the Engine with a force equal to the pressure of the atmosphere. As air cannot be condensed, like steam, the vacuum would be destroyed, and there would consequently be an equal pressure on each side of the piston. The result in such case, would be a stoppage of the Engine.

EXPANSION OF STEAM.

EXPANSION of steam takes place when the communication with the Boiler is cut off from the cylinder of the Engine, after the piston has travelled a portion of its stroke. The steam thus enclosed betwixt the piston and top (or bottom) of the cylinder, forces the piston forward to the end of the stroke. Supposing the valve to have closed when the piston had travelled one-fourth the length of the cylinder, and its pressure at that time to be 20lbs above atmosphere on each square inch, or 35lbs the total pressure per square inch upon the piston, it would begin to decrease in pressure as the piston were forced forward, till the piston reached the end of the stroke, when the pressure would be 8¾lbs per square inch. For one-fourth the length of the cylinder, the pressure would be 35lbs per square inch; that is, while the communication between the Boiler and the face of the piston remained open. This communication being closed at that point, the steam would begin to expand, forcing the piston forward. When the latter arrived at half stroke, or at the half length of the cylinder, the pressure would be 17½lbs upon the square inch; when it arrrived at three-fourths the length of the cylinder, the pressure upon it would be 12¾lbs per square inch; and at the end of the stroke the pressure would be 8¾lbs per square inch, or 6¼lbs per square inch below the pressure of the atmosphere—the steam having gradually expanded during the traverse of the piston, from 35lbs at the commencement and up to one-fourth of that traverse, down to 8¾lbs at the termination of the stroke—leaving only the latter amount of steam to be condensed.

Expansion is, perhaps, the most extraordinary property of steam. The merit of the discovery is due to HORNBLOWER, who, in 1781, obtained a patent for the invention. He states that when steam is confined on one side of a piston, and a partial vacuum is formed on the other, the steam will move the piston till its force is in equilibrium with the friction and uncondensed steam on the under side of the piston, and power is

communicated during the motion, in addition to the ordinary effect of the original steam pressure. To apply this power, which was *lost* before, HORNBLOWER used two cylinders in which the steam was to act. He employed the steam, after it had acted in the first cylinder, to operate a second time in the second and larger cylinder, by permitting it to expand. This he accomplished by connecting the cylinders together by proper apertures. We give his own description in the words of his specification :—"I employ the steam after it has acted in the first vessel to operate a second time on the other, by permitting it to expand itself, which I do by connecting the two vessels together."

The expansive property of steam is strictly mechanical, and is a property common to all fluids—air, gas, &c. It simply consists in this—that vapour of a given elastic force will expand to certain limits, and during the process of expansion will act on opposing bodies with a force gradually decreasing, causing a diminution of elastic power in an inverse ratio to the increase of volume, until it has reached the limits of its power, or is counterbalanced by the resistance of a surrounding medium. Thus, steam of any given pressure, expanded to twice its original bulk, will exert only one half its original power. If a partial vacuum be formed on one side of a piston, its motion will be continued until the density of the steam on the other side be as low as that of the uncondensed vapour on the vacuum side of the piston. It is clear that the power which may be obtained by thus impelling a piston will be the average between the highest and the lowest pressure upon the piston. It must also be understood that IT IS A SAVING, AND NOT A GAIN, that thus results from expansion : a power being made available which was before lost, by using the steam up to its last impelling force, and not allowing it to escape until the whole of that available force has been expended. This accounts for some Engines using more fuel and steam than others, because the steam is not expanded to its utmost limit, in consequence of the steam not being cut off by the valve soon enough ; or that the load on the Engine is great, and requires the steam to be longer on the piston before it is cut off. If the load on the Engine be such as to allow the steam to be cut off early, and to expand to its full available limits in the cylinder, then the most will have been made of it ; the highest pressure in the Boiler will have been used upon the piston, and down to the lowest point. Were atmospheric air compressed so as to exert a force of 20lbs on the square inch, and were the supply to be continued throughout the stroke, an impulse would be given to the piston equal to 20lbs to the square inch during the whole stroke ; but if the air was allowed to expand, the impulse would only be as the average, or 10lbs. It will be evident that, if in the former case the air was suffered

to depart from the cylinder at the same elasticity as that which it entered, we should lose the force which was necessary to compress it to its density; while, by expanding it to its limits, we apply every part of that force. The main spring of a watch actuates its machinery in this manner:—an increasing effort is required to wind up the spring, and a decreasing impulse is given back to the machinery. But, if after the spring had partially uncoiled itself, it were then liberated, the force which wound it up to its last impelling point would be totally lost. So in the Steam Engine: if the steam be allowed to escape from the cylinder before its force is expended by expanding to the lowest available pressure, the loss will be in proportion to the amount of the pressure not made available.

A certain quantity of fuel is required to raise steam to a certain elasticity. If that steam be allowed, after having moved the piston, to escape into the atmosphere or condenser without having acted expansively, a portion of the fuel which was consumed to raise the steam up to that point of elasticity will have been lost. In one case a given bulk of fuel would produce fifty: in the other case it would produce fifty, added to all the intermediates down to the lowest expansive force.

By this it will be apparent that the advantages arising from expansion increase with the density of the steam. In round numbers, 65 of high-pressure steam will perform more than seven times the duty of 25 of low-pressure steam: a fact greatly in favour of high-pressure steam and expansion. In Condensing Engines the steam expands to half an atmosphere, and sometimes below. In Non-condensing Engines the steam expands to one or two pounds above atmosphere, but often not so low. This entails a loss in proportion to the pressure of the steam thrown into the atmosphere.

WORKING STEAM EXPANSIVELY IN ONE CYLINDER.

THERE are two modes of applying the power of steam to the working cylinder, namely: one, allowing steam to flow from the Boiler during the whole length of the stroke; and the other, cutting it off from the Boiler when the piston has travelled a determined distance—the great and paramount object of this last arrangement being a saving of fuel.

If steam be applied the full length of the stroke, the average pressure will be as the pressure per square inch upon the piston; but if the steam be cut off at half stroke—suppose the pressure to be 65lbs per inch when the pressure of the atmosphere is added—there will be a mean equivalent, or average pressure, throughout the stroke of 55lbs per square inch;

being only 10lbs less than the full pressure, or 16 per cent. of a loss in power, though half the former quantity of steam has only been used. This alone effects a saving of 34 per cent. in fuel, and shows the great benefit to be derived from expansion in one cylinder.

If this principle be true—and its truth is undeniable—it is quite evident that the greatest economy will result from extending expansion to its full limit, and making the cylinders of Steam Engines of sufficient capacity for this purpose; though with the high-pressures with which expansion is most available, they will require to be less than are usually made, to allow the Engines to produce the maximum effect. The table which follows this section shows, according to the pressure used, the average pressure of steam upon the piston when cut off at any portion of the stroke. The table begins at 10lbs above atmosphere, and advances in 5lbs up to 150lbs per square inch. This table will enable the Engineer to determine, by any given pressure, the amount of expansion required for the power to be obtained, and the saving thereby to be effected.

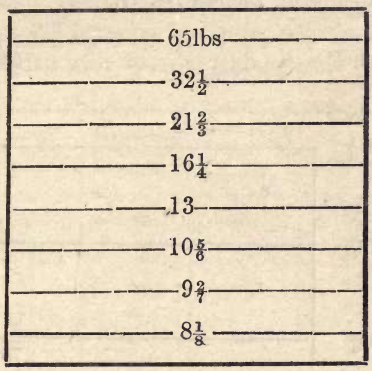
The principle of expanding the steam in the Condensing Engine is the same as in the Non-condensing Engine, excepting that the steam, which exhausts into the atmosphere, cannot expand below 15lbs per square inch, because the exhaust is open to the pressure of the atmosphere in all cases. The resistance of the atmosphere (15lbs) must be added to the pressure of steam above atmospheric pressure, when calculating the pressure of the expansion of steam upon the piston. For example: steam at 20lbs pressure above the atmosphere upon the piston, cut off at one-fourth the stroke, will be $8\frac{3}{4}$lbs at the termination of the stroke, as shown by the following calculation:—20lbs added to 15lbs, the pressure of the atmosphere, equals 35lbs. This divided by four, gives the quotient $8\frac{3}{4}$lbs. Thus, $8\frac{3}{4}$lbs is the pressure at the termination of the stroke, or $6\frac{1}{4}$lbs below atmospheric pressure. The diagram which follows,—No. 16, and the explanation,—illustrate the principle more fully.

A represents the cylinder of a Steam Engine, divided into eight equal parts. The pressure of the steam used is supposed to be 50lbs per square inch above the pressure of the atmosphere. Suppose the steam to be cut off at one-eighth the stroke, and the piston to be travelling the other seven portions by the force of the expanding steam: in calculating what will be the pressure at the termination or at any other portion of the stroke, add the pressure of the atmosphere to the pressure of the steam above atmospheric pressure. Thus, in this case: 50lbs added to 15lbs, equals 65; this divided by 8, gives $8\frac{1}{8}$. To make this rule more perfectly understood, let the Engineman add together the pressure of the steam and that of the atmosphere, and divide by the number of expansions, and the quotient will give him the pressure on the piston at the

end of the stroke. For the average on the piston throughout the stroke, see the accompanying table; which average will be found to be 25lbs throughout the whole of the stroke.

Diagram No. 16.

A



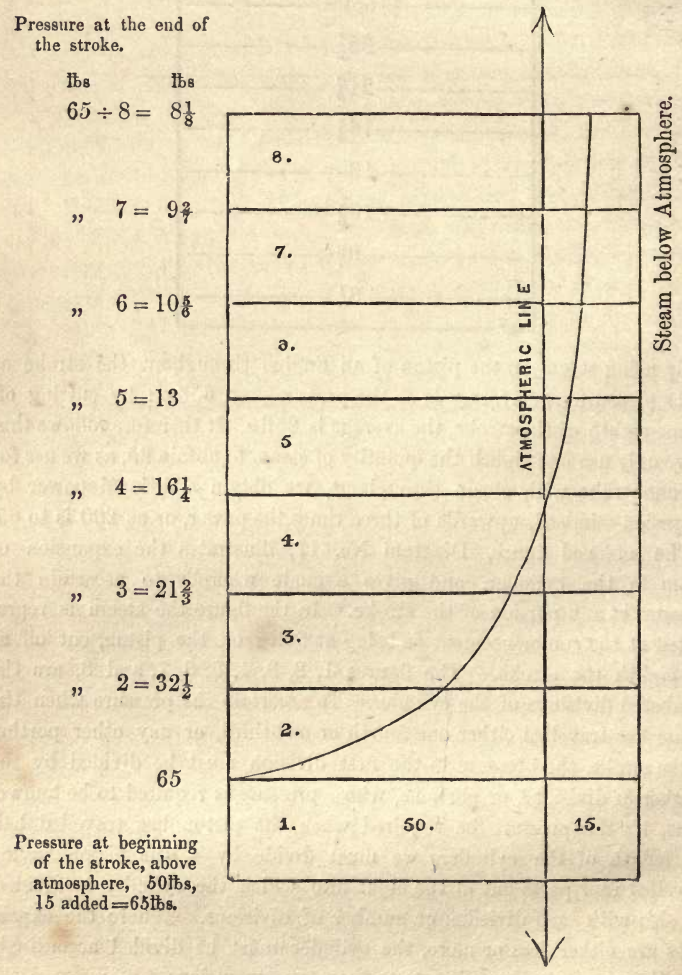
By using steam on the piston of an Engine throughout the stroke at 65lbs pressure, the average is as the pressure, or 65lbs : by cutting off at one-eighth of the stroke, the average is 25lbs. It therefore follows that as we only use one-eighth the quantity of steam to obtain 25, as we use for the one stroke with steam throughout, we obtain additional power by expansion—indeed, upwards of three times the power, or as 200 is to 65.

The annexed figure, Diagram No. 17, illustrates the expansion of steam in the cylinder, and gives a mode whereby to ascertain the pressure at any portion of the stroke. In the figure the steam is represented at the commencement as being at 65lbs on the piston, cut off at one-eighth the stroke. The figures 1, 2, 3, 4, 5, 6, 7, and 8, are the numbered divisions of the cylinder. To ascertain the pressure when the piston has travelled either one-fourth or one-third, or any other portion of the stroke, the pressure in the first division must be divided by the number of divisions, or portions, whose pressure is required to be known. Thus, if the pressure be required when the piston has travelled half the length of the cylinder, we must divide by 4, the piston having travelled four parts out of the eight into which the cylinder is divided. So also with each division, or number of divisions. Where the expansions are either less or more, the cylinder must be divided accordingly into the same number of parts as there are expansions.

For example : steam at 20lbs above the atmospheric pressure, cut off at one-third of the stroke, will be, at the end of the stroke, 11⅔lbs ; thus, 20lbs of steam and 15lbs atmospheric pressure equals 35lbs cut off

at one-third—is $3 \div 35 = 11{\cdot}2$, or nearly 4lbs below atmosphere. If a High-pressure Engine, the pressure of the atmosphere must be added in the same way. Example: 80lbs cut off at one-sixth the length of the cylinder: 80 added to 15, equals 95; 6 in $95 = 15{\cdot}5$. The steam in

Diagram No. 17.



this case will have expanded down to the pressure of the atmosphere within five-sixths of a pound, and therefore will have been practically used up in a Non-condensing Engine before it is allowed to escape. In

a Condensing Engine, the 15·5lbs would, in practice, expand down to 5lbs or 10lbs below atmosphere : the difference being power lost in a Non-condensing Engine.

In using steam of high-pressure, another advantage is obtained, inasmuch as it requires proportionately less fuel for the generation of increased high-pressure steam. The cost of the raw material, or fuel, for steam at various pressures will hereafter be shown, and the saving effected by generating and working with steam at high-pressure will be noted.

Steam on.		Quantity of steam used.	Pressure of steam above atmosphere.	Pressure of steam with the atmosphere.	Power obtained.	Pressure of steam at the end of the stroke.
Full length		100	80lbs	95lbs	100	95lbs
Cut off at	$\frac{7}{8}$	$87\frac{1}{2}$	...	...	97	83
	$\frac{3}{4}$	75	...	...	95	71
	$\frac{5}{8}$	$62\frac{1}{2}$	...	...	92	59
	$\frac{1}{2}$	50	...	...	84	$47\frac{1}{2}$
	$\frac{3}{8}$	$37\frac{1}{2}$	...	...	71	$31\frac{1}{2}$
	$\frac{1}{4}$	25	...	...	60	$23\frac{1}{2}$
	$\frac{1}{8}$	$12\frac{1}{2}$	...	...	37	$11\frac{3}{4}$

The accompanying table shows the quantity of steam used when worked without expansion, and the power obtained ; also the quantity when worked expansively, varying from $\frac{7}{8}$ to $\frac{1}{8}$ the cut-off, and the pressure of the steam at the termination of the stroke. It will be observed that in proportion as the steam is expanded to the greatest limit, so is the saving : the principle of expansion being a *saving*, and not a gain. But the whole of the steam is made available when expansion is carried to its full extent. Thus, if steam at 60lbs, or any other pressure, be brought upon the piston, and cut off at a point to enable it to expand to the lowest practical limit, the most will have been made of it, although the expansion has been effected in one cylinder.

When the steam passes through a number of cylinders, there is a loss by condensation and friction, particularly if the pressure be high. The conducting properties of the metal rob the steam of its heat in proportion to the difference of the temperature. Hence the necessity of clothing high-pressure cylinders and pipes with felt, or other non-conducting substance, to prevent the absorption of the caloric ; or of casing them, keeping steam in the casings at the pressure of the Boiler. The higher the temperature at which the cylinders of Steam Engines can be maintained, the better.

A TABLE,

Shewing the average Pressure of the Steam upon the Piston throughout the Stroke, when cut off in the Cylinder from $\frac{1}{3}$ to $\frac{1}{1\frac{1}{2}}$, commencing with 10lbs and advancing in 5lbs up to 150lbs Pressure.

Steam Cut off in the Cylinder.	Pressure in lbs. at the commencement of the Stroke.														
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
	Average Pressure in lbs. upon the Piston.														
$\frac{1}{3}$	7	$10\frac{1}{2}$	$14\frac{1}{2}$	$17\frac{1}{2}$	21	$24\frac{1}{2}$	28	$31\frac{1}{2}$	35	$38\frac{1}{2}$	42	$45\frac{1}{2}$	49	$52\frac{1}{2}$	1
$\frac{2}{5}$	$9\frac{1}{4}$	14	$18\frac{3}{4}$	$23\frac{1}{2}$	$28\frac{1}{4}$	$32\frac{3}{4}$	$37\frac{1}{2}$	42	$46\frac{3}{4}$	$51\frac{1}{2}$	$56\frac{1}{4}$	61	$65\frac{1}{2}$	$70\frac{1}{4}$	2
$\frac{1}{4}$	6	9	12	15	$17\frac{3}{4}$	$20\frac{3}{4}$	$23\frac{3}{4}$	$26\frac{3}{4}$	$29\frac{3}{4}$	$32\frac{3}{4}$	$35\frac{3}{4}$	$38\frac{3}{4}$	$41\frac{3}{4}$	$44\frac{3}{4}$	3
$\frac{1}{2}$	$8\frac{1}{2}$	$12\frac{3}{4}$	17	21	$25\frac{1}{4}$	$29\frac{1}{2}$	$33\frac{3}{4}$	38	$42\frac{1}{4}$	$46\frac{1}{2}$	$50\frac{3}{4}$	55	$59\frac{1}{4}$	$63\frac{1}{2}$	4
$\frac{3}{4}$	$9\frac{1}{2}$	$14\frac{1}{2}$	$19\frac{1}{4}$	24	$28\frac{3}{4}$	$33\frac{1}{2}$	$38\frac{1}{2}$	$43\frac{1}{4}$	$48\frac{1}{4}$	53	$57\frac{3}{4}$	$62\frac{1}{2}$	$67\frac{1}{2}$	$72\frac{1}{4}$	5
$\frac{1}{5}$	$5\frac{1}{4}$	$7\frac{3}{4}$	$10\frac{1}{2}$	13	$15\frac{1}{2}$	$18\frac{1}{4}$	$20\frac{3}{4}$	$23\frac{1}{2}$	26	$28\frac{1}{4}$	$31\frac{1}{4}$	34	$36\frac{1}{2}$	39	6
$\frac{2}{5}$	$7\frac{1}{2}$	$11\frac{1}{2}$	$15\frac{1}{4}$	19	23	$26\frac{3}{4}$	$30\frac{1}{2}$	$34\frac{1}{2}$	$38\frac{1}{4}$	42	46	$49\frac{3}{4}$	$53\frac{1}{2}$	$57\frac{1}{2}$	7
$\frac{3}{5}$	9	13	18	$22\frac{1}{2}$	27	$31\frac{1}{2}$	$36\frac{1}{4}$	$40\frac{3}{4}$	$45\frac{1}{4}$	$49\frac{3}{4}$	$54\frac{1}{4}$	$58\frac{3}{4}$	$63\frac{1}{4}$	$67\frac{3}{4}$	8
$\frac{4}{5}$	$9\frac{3}{4}$	$14\frac{1}{2}$	$19\frac{1}{2}$	$23\frac{3}{4}$	$29\frac{1}{4}$	$34\frac{1}{4}$	39	44	49	$53\frac{3}{4}$	$58\frac{1}{2}$	$63\frac{1}{2}$	$68\frac{1}{2}$	$73\frac{3}{4}$	9
$\frac{1}{6}$	$4\frac{1}{2}$	7	$9\frac{1}{4}$	$11\frac{1}{2}$	14	$16\frac{1}{4}$	$18\frac{1}{2}$	$20\frac{3}{4}$	$23\frac{1}{4}$	$25\frac{1}{2}$	$27\frac{3}{4}$	$30\frac{1}{4}$	$32\frac{1}{2}$	$34\frac{3}{4}$	10
$\frac{5}{6}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{1}{2}$	$29\frac{1}{2}$	$34\frac{1}{2}$	$39\frac{1}{2}$	$44\frac{1}{4}$	$49\frac{1}{4}$	54	59	64	69	$73\frac{3}{4}$	11
$\frac{1}{7}$	$4\frac{1}{4}$	$6\frac{1}{4}$	$8\frac{1}{4}$	$10\frac{1}{2}$	$12\frac{1}{2}$	$14\frac{3}{4}$	$16\frac{3}{4}$	$18\frac{3}{4}$	21	$23\frac{1}{4}$	$25\frac{1}{4}$	$27\frac{1}{4}$	$29\frac{1}{2}$	$31\frac{1}{2}$	12
$\frac{2}{7}$	$6\frac{1}{2}$	$9\frac{1}{2}$	$12\frac{3}{4}$	16	$19\frac{1}{4}$	$22\frac{1}{2}$	$25\frac{3}{4}$	$28\frac{3}{4}$	32	$35\frac{1}{4}$	$38\frac{1}{2}$	$41\frac{3}{4}$	45	$48\frac{1}{4}$	13
$\frac{3}{7}$	$7\frac{3}{4}$	$11\frac{3}{4}$	$15\frac{3}{4}$	$19\frac{3}{4}$	$23\frac{3}{4}$	$27\frac{3}{4}$	$31\frac{1}{2}$	$35\frac{1}{2}$	$39\frac{1}{2}$	$43\frac{1}{2}$	$47\frac{1}{2}$	$51\frac{1}{2}$	$55\frac{1}{4}$	$59\frac{1}{4}$	14
$\frac{4}{7}$	$8\frac{3}{4}$	$13\frac{1}{4}$	$17\frac{3}{4}$	$22\frac{1}{4}$	$26\frac{3}{4}$	$31\frac{1}{4}$	$35\frac{1}{2}$	40	$44\frac{1}{2}$	49	$53\frac{1}{2}$	$57\frac{3}{4}$	$62\frac{1}{2}$	$66\frac{3}{4}$	15
$\frac{5}{7}$	$9\frac{1}{2}$	$14\frac{1}{4}$	19	$23\frac{3}{4}$	$28\frac{1}{2}$	$33\frac{1}{2}$	$38\frac{1}{4}$	$42\frac{3}{4}$	$47\frac{3}{4}$	$52\frac{1}{2}$	$57\frac{1}{4}$	62	$66\frac{3}{4}$	$71\frac{1}{2}$	16
$\frac{6}{7}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{3}{4}$	$29\frac{1}{2}$	$34\frac{1}{2}$	$39\frac{1}{2}$	$44\frac{1}{2}$	$49\frac{1}{2}$	$54\frac{1}{4}$	$59\frac{1}{4}$	$63\frac{3}{4}$	$69\frac{1}{4}$	$74\frac{1}{4}$	17
$\frac{1}{8}$	$3\frac{3}{4}$	$5\frac{3}{4}$	$7\frac{3}{4}$	$9\frac{1}{2}$	$11\frac{1}{2}$	$13\frac{1}{2}$	$15\frac{1}{4}$	$17\frac{1}{4}$	$19\frac{1}{4}$	$21\frac{1}{4}$	23	25	27	$28\frac{3}{4}$	18
$\frac{3}{8}$	$7\frac{1}{4}$	11	$14\frac{3}{4}$	$18\frac{1}{2}$	$22\frac{1}{4}$	26	$29\frac{3}{4}$	$33\frac{1}{2}$	37	$40\frac{3}{4}$	$44\frac{1}{2}$	$48\frac{1}{4}$	52	$55\frac{3}{4}$	19
$\frac{5}{8}$	$9\frac{1}{4}$	$13\frac{3}{4}$	$18\frac{1}{4}$	$22\frac{3}{4}$	$27\frac{1}{2}$	32	$36\frac{3}{4}$	$41\frac{1}{4}$	$45\frac{1}{2}$	$50\frac{1}{2}$	$55\frac{1}{4}$	$59\frac{3}{4}$	$64\frac{1}{4}$	$68\frac{3}{4}$	20
$\frac{7}{8}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{3}{4}$	$29\frac{3}{4}$	$34\frac{3}{4}$	$39\frac{1}{2}$	$44\frac{1}{2}$	$49\frac{1}{2}$	$54\frac{1}{2}$	$59\frac{1}{2}$	$64\frac{1}{2}$	$69\frac{1}{4}$	$74\frac{1}{4}$	21
$\frac{1}{9}$	$3\frac{1}{2}$	$5\frac{1}{4}$	7	$8\frac{3}{4}$	$10\frac{1}{2}$	$12\frac{1}{4}$	$14\frac{1}{4}$	$15\frac{3}{4}$	$17\frac{3}{4}$	$19\frac{1}{4}$	$21\frac{1}{4}$	23	$24\frac{3}{4}$	$26\frac{1}{2}$	22
$\frac{2}{9}$	$5\frac{1}{2}$	$8\frac{1}{4}$	11	$13\frac{3}{4}$	$16\frac{1}{2}$	$19\frac{1}{4}$	$22\frac{1}{4}$	25	$27\frac{3}{4}$	$30\frac{1}{2}$	$33\frac{1}{4}$	36	$38\frac{3}{4}$	$41\frac{3}{4}$	23
$\frac{4}{9}$	8	12	16	20	24	28	32	36	$40\frac{1}{4}$	$44\frac{1}{4}$	$48\frac{1}{4}$	$52\frac{1}{4}$	$56\frac{1}{4}$	$60\frac{1}{4}$	24
$\frac{5}{9}$	$8\frac{3}{4}$	$13\frac{1}{4}$	$17\frac{1}{2}$	22	$26\frac{1}{4}$	$30\frac{3}{4}$	$35\frac{1}{4}$	$39\frac{1}{2}$	44	$48\frac{1}{2}$	$52\frac{3}{4}$	$56\frac{1}{2}$	$61\frac{3}{4}$	66	25
$\frac{7}{9}$	$9\frac{1}{2}$	$14\frac{1}{2}$	$19\frac{1}{4}$	$24\frac{1}{4}$	29	34	$38\frac{3}{4}$	$43\frac{3}{4}$	$48\frac{1}{2}$	$53\frac{1}{2}$	$58\frac{1}{4}$	$63\frac{1}{4}$	68	$72\frac{3}{4}$	26
$\frac{8}{9}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{3}{4}$	$29\frac{3}{4}$	$34\frac{3}{4}$	$39\frac{3}{4}$	$44\frac{1}{2}$	$49\frac{1}{2}$	$54\frac{1}{2}$	$59\frac{1}{2}$	$64\frac{1}{2}$	$69\frac{1}{2}$	$74\frac{1}{2}$	27
$\frac{1}{11}$	3	$4\frac{1}{2}$	6	$7\frac{3}{4}$	$9\frac{1}{4}$	$10\frac{3}{4}$	$12\frac{1}{4}$	$13\frac{3}{4}$	$15\frac{1}{4}$	$16\frac{3}{4}$	$18\frac{1}{2}$	20	$21\frac{1}{2}$	23	28
$\frac{2}{11}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$9\frac{3}{4}$	$12\frac{1}{4}$	$14\frac{3}{4}$	$17\frac{1}{4}$	$19\frac{1}{2}$	22	$24\frac{1}{2}$	27	$29\frac{1}{2}$	$31\frac{3}{4}$	$34\frac{1}{4}$	$36\frac{3}{4}$	29
$\frac{3}{11}$	$6\frac{1}{4}$	$9\frac{1}{4}$	$12\frac{1}{2}$	$15\frac{1}{2}$	$18\frac{3}{4}$	$21\frac{3}{4}$	25	28	$31\frac{1}{4}$	$34\frac{1}{4}$	$37\frac{1}{2}$	$40\frac{3}{4}$	$43\frac{3}{4}$	47	30
$\frac{4}{11}$	$7\frac{1}{4}$	$10\frac{3}{4}$	$14\frac{1}{2}$	$18\frac{1}{4}$	$21\frac{3}{4}$	$25\frac{1}{2}$	$29\frac{1}{4}$	$32\frac{3}{4}$	$36\frac{1}{2}$	$40\frac{1}{4}$	$43\frac{3}{4}$	$47\frac{1}{2}$	51	$54\frac{3}{4}$	31
$\frac{5}{11}$	8	12	$16\frac{1}{4}$	$20\frac{1}{4}$	$24\frac{1}{4}$	$28\frac{1}{4}$	$32\frac{1}{2}$	$36\frac{1}{2}$	$40\frac{1}{2}$	$44\frac{1}{2}$	$48\frac{3}{4}$	$52\frac{3}{4}$	$56\frac{3}{4}$	$60\frac{3}{4}$	32
$\frac{6}{11}$	$8\frac{3}{4}$	13	$17\frac{1}{2}$	$21\frac{3}{4}$	$26\frac{1}{4}$	$30\frac{1}{2}$	35	$39\frac{1}{4}$	$43\frac{3}{4}$	48	$52\frac{1}{2}$	$56\frac{3}{4}$	$61\frac{1}{4}$	$65\frac{1}{2}$	33
$\frac{7}{11}$	$9\frac{1}{4}$	$13\frac{3}{4}$	$18\frac{1}{4}$	23	$27\frac{1}{2}$	$32\frac{1}{4}$	$36\frac{3}{4}$	$41\frac{1}{2}$	46	$50\frac{3}{4}$	$55\frac{1}{4}$	60	$64\frac{1}{2}$	$69\frac{1}{4}$	34
$\frac{8}{11}$	$9\frac{1}{2}$	$14\frac{1}{4}$	19	$23\frac{3}{4}$	$28\frac{3}{4}$	$33\frac{1}{2}$	$38\frac{1}{4}$	43	$47\frac{3}{4}$	$52\frac{3}{4}$	$57\frac{1}{2}$	$62\frac{1}{4}$	67	$71\frac{3}{4}$	35
$\frac{9}{11}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{1}{2}$	$24\frac{1}{2}$	$29\frac{1}{4}$	$34\frac{1}{4}$	$39\frac{1}{4}$	44	49	54	$58\frac{3}{4}$	$63\frac{3}{4}$	$68\frac{3}{4}$	$73\frac{1}{2}$	36
$\frac{10}{11}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{3}{4}$	$29\frac{3}{4}$	$34\frac{3}{4}$	$39\frac{3}{4}$	$44\frac{3}{4}$	$49\frac{3}{4}$	$54\frac{3}{4}$	$59\frac{3}{4}$	$64\frac{1}{2}$	$69\frac{1}{4}$	$74\frac{1}{2}$	37
$\frac{1}{1\frac{1}{2}}$	$2\frac{3}{4}$	$4\frac{1}{4}$	$5\frac{3}{4}$	$7\frac{1}{4}$	$8\frac{1}{2}$	10	$11\frac{1}{2}$	13	$14\frac{1}{2}$	$15\frac{3}{4}$	$17\frac{1}{4}$	$18\frac{3}{4}$	$20\frac{1}{4}$	$21\frac{3}{4}$	38
$\frac{7}{1\frac{1}{2}}$	$8\frac{1}{4}$	$12\frac{1}{2}$	$16\frac{3}{4}$	21	$25\frac{1}{4}$	$29\frac{1}{2}$	$33\frac{3}{4}$	38	$42\frac{1}{4}$	$46\frac{1}{2}$	$50\frac{3}{4}$	55	$59\frac{1}{4}$	$63\frac{1}{2}$	39
$\frac{11}{1\frac{1}{2}}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{3}{4}$	$29\frac{3}{4}$	$34\frac{3}{4}$	$39\frac{3}{4}$	$44\frac{3}{4}$	$49\frac{3}{4}$	$54\frac{3}{4}$	$59\frac{3}{4}$	$64\frac{3}{4}$	$69\frac{3}{4}$	$74\frac{3}{4}$	40

A TABLE,

Shewing the average Pressure of the Steam upon the Piston throughout the Stroke, when cut off in the Cylinder from $\frac{1}{8}$ to $\frac{1}{12}$, commencing with 10lbs and advancing in 5lbs up to 150lbs Pressure.

	Pressure in lbs. at the commencement of the Stroke.														
	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
	Average Pressure in lbs. upon the Piston.														
1	56	59½	63	66½	70	73	77½	80½	84	87½	91	94½	98	101½	105
2	75	79½	84½	89	93¾	98¼	103	107¾	112½	117	121¾	126½	131	135¾	140½
3	47¾	50¾	53¾	56¾	59¾	62¾	65½	68½	71½	74½	77½	80½	83½	86½	89½
4	67¾	72	76¼	80½	84¾	89	93¼	97¼	101½	105¾	110	114¼	118½	122¾	127
5	77¼	82	87	91¾	96½	101¼	106¼	111	115¾	120¾	125½	130¼	135¼	140	144¾
6	41¾	44¼	47	49½	52¼	54¾	57¼	60	62½	65¼	67¾	70½	73	75½	78½
7	61¼	65	69	72¾	76½	80¼	84¼	88	91¾	95¾	99½	103¼	107¼	111	115
8	72½	77	81½	86	90½	95¼	99½	104¼	108¾	113¼	117¾	122¼	126¾	131½	135
9	78¼	83	88	92¾	97¾	102¾	107½	112½	117½	122¼	127¼	132	136¾	141¾	146¾
10	37¼	39½	41¾	44¼	46½	48¾	51¼	53½	55¾	58	60½	62¾	65	67½	69¾
11	78¾	83¾	88¾	93½	98½	103½	108¾	113¼	118¼	123¼	128	133	137¾	142¾	147
12	33½	35¾	37¾	40	42	44	46¼	48¼	50½	52½	54¾	56¾	58¾	61	63
13	51½	54½	57¾	61	64¼	67½	70¾	74	77¼	80½	83½	86¾	90	93¼	96½
14	63¼	67¼	71¼	75¼	79	83	87	91	94¾	98¾	102¼	106¾	110¾	114¾	118¾
15	71¼	75¾	80	84½	89	93½	98	102½	106¾	111½	115¾	120¼	124¾	129¼	133½
16	76¼	81	85¾	90¾	95½	100¼	105	109¾	114½	119¼	124	128¾	133½	138½	143¼
17	79	84	89	93¾	98¾	103¾	108¾	113¾	118¾	123½	128½	133½	138½	143½	148¼
18	30¾	32¾	34½	36½	38½	40½	42¾	44½	46¼	48	50	52	54¼	56½	57¾
19	59½	63	66¾	70½	74¼	78	81¾	85½	89	92¾	96½	100½	104	107¾	111½
20	73½	78	82½	87¼	91¾	96½	101	105½	110¼	114¾	119½	124	128½	133¼	137¾
21	79¼	84¼	89¼	94¼	99	104	109	114	119	124	128¾	133¾	138¾	143¾	148¾
22	28¼	30¼	31¾	33¾	35½	37¼	39	40¾	42½	44¼	46	47¾	49½	51½	53¼
23	44½	47¼	55	57¾	55½	58¼	61	63¾	66¾	69½	72¼	75	77¾	79½	83
24	64½	68¼	72¼	76¼	80½	84½	88½	92½	96½	100½	104½	108½	112½	116½	120½
25	70½	74¾	79¼	83¾	88	92½	97	101¼	105¾	110¼	114½	119	123½	127¾	132¼
26	77¾	82¾	87½	92¼	97¼	102	107	111¾	116¾	121½	126½	131¼	136¼	141	145
27	79¼	84¼	89¼	94¼	99¼	104¼	109¼	114¼	119¼	124	129	134	139	144	149
28	24½	26¼	27¾	29¼	30¾	32¼	33¾	35½	37	38½	40	41½	43¼	44¾	46¼
29	39¼	41¾	44¼	46¾	49	51½	54	56½	59	61¼	63¾	66¼	68¾	71¼	73¾
30	50	53¼	56¼	59½	62½	65¾	68¾	72	75¼	78¼	81½	84½	87¾	90¾	94
31	58½	62	65¾	69½	73	76¾	80¼	84	87¾	91¼	95	98½	102¼	106	109½
32	65	69	73	77	81¼	85¼	89¼	93½	97½	101½	105½	109¾	113¾	117¾	121¾
33	70	74¼	78¾	83	87½	91¾	96¼	100¾	105	109½	113¾	118¼	122½	127	131
34	73¾	78½	83	87¾	92¼	97	101½	106¼	110¾	115½	120	124¾	129¼	133¾	138½
35	76¾	81½	86¼	91	95¾	100½	105¼	110¼	115	119¾	124½	129¼	134¼	139	143½
36	78½	83½	88¼	93¼	98¼	103	108	112¾	117¾	122¾	127½	132½	137½	142¼	147¼
37	79½	84½	89½	94½	99½	104½	109½	114½	119¼	124¼	129¼	134¼	139¼	144¼	149¼
38	23¼	24½	26	27½	29	30½	31¾	33¼	34¾	35¼	37¾	39	40½	42	43½
39	67¾	72	76¼	80½	84¾	89	93¼	97½	101½	105¾	110	114¼	118½	122¾	127
40	79½	84½	89½	94½	99½	104½	109½	114½	119½	124½	129½	134½	139½	144½	149¼

THE FOREGOING TABLE

SHOWS, according to the pressure used, the average pressure of steam upon the piston, cut off at any portion of the stroke, beginning at 10lbs, and advancing in 5lbs up to 150lbs per square inch; enabling the Engineer to determine, at any given pressure, the amount of expansion requisite for the full power to be obtained, and the saving thereby to be effected. In all cases the pressure of the atmosphere must be added to the pressure of the steam above atmosphere, when reference is made to the table for the average throughout the stroke.

Example: 15lbs pressure on the piston above atmosphere, cut off at one-fourth the piston's traverse, will be thus: 15lbs steam and 15lbs the pressure of the atmosphere = 30 : then look for 30lbs at the head of the table, and down the first column for $\frac{1}{4}$; trace that $\frac{1}{4}$ under 30, and you will find the average to be $17\frac{3}{4}$lbs throughout the stroke. For other proportions follow the same principle—that is, supposing the vacuum to be 15lbs. If there be not 15lbs of a vacuum, the amount of pressure below must be deducted from the average.

If a Non-condensing Engine, where the steam is expanded into the atmosphere, the case will be different: because the steam cannot expand below 15lbs to the square inch,—that being the pressure of the atmosphere.

Example: 45lbs steam above atmosphere upon the piston of a High-pressure Engine, cut off at one-fourth the length of the stroke. The average pressure throughout will be—allowing 1lb for friction and back-pressure to force out the steam in the cylinder—$19\frac{3}{4}$lbs. Thus: 45lbs steam cut off at one-fourth the stroke, with 15lbs added, make 60lbs. Look for 60 on the top line of the table, and $\frac{1}{4}$ on the side. Trace that $\frac{1}{4}$ to the figures under 60, and the average will be found to be $35\frac{3}{4}$lbs. Take 16lbs from $35\frac{3}{4}$lbs, for atmospheric pressure and friction, and there remains $19\frac{3}{4}$lbs—the available average pressure on the piston.

Example: 30lbs cut off at one-third. Add 15, = 45. The average in the table will be $31\frac{1}{2}$: deduct 16lbs, and there remain $15\frac{1}{2}$lbs, the available average pressure upon the piston.

Another Example: 15lbs cut off at half-stroke. Add 15, = 30. The average in the table will be $25\frac{1}{4}$. Deduct 16lbs and $9\frac{1}{4}$lbs remain, the average available pressure.

In these examples the steam in the cylinder has expanded to atmospheric pressure.

In proportion to the pressure of the steam, the cut-off will have to be varied, as shown by the examples, if the steam is to be expanded to its full limit in the cylinder of a Non-condensing Engine; that is, down to 15lbs, or equal to the pressure of the atmosphere.

NOMINAL AND INDICATED HORSE-POWER OF STEAM ENGINES.

THE nominal horse-power of a Steam Engine, as laid down by JAMES WATT, the inventor of the *Steam Engine Indicator*, is 33,000lbs raised one foot high per minute, or any less weight a proportionately greater height in the same space of time. Upon this calculation he defined the power exerted. His first premise was to ascertain the average pressure of steam upon the piston; and for this, as a standard, he laid down, as a rule, an available pressure of 7lbs per square inch. The speed of the piston he computed at 220 feet per minute. These, in his day, were about the average pressure and speed Steam Engines were worked at. Thus, a Steam Engine with a cylinder 26 inches diameter, with an average pressure of steam and vacuum* on the piston of 7lbs per square inch—when the friction of the Engine is deducted—travelling 220 feet per minute, will be of twenty-four horse-power, or, as it is termed, a twenty-four horse Engine. It would, in fact, be no more when worked at the before-named pressure and speed; that is, it would exert no more than twenty-four horse-power. This then is, nominally, a twenty-four horse Engine; and were the *Indicator* to be applied, it would show the Engine to be working not more than twenty-four available horse-power; for the "indicated" horse-power in this case would be *precisely* the same as the "nominal"—viz., 33,000lbs raised one foot high per minute.

The term "*nominal* horse-power" is used because we ascertain originally the power of an Engine by calculation on the basis above laid down; and when we say "*indicated* horse-power," it is because we ascertain the power by means of the instrument known as the *Indicator*. A horse-power, whether termed "nominal" or "indicated," is therefore nothing more nor less than 33,000lbs raised to the height before described—independently of the friction of the Engine.

But let us suppose the same Engine to be worked at an increased pressure—say at 30lbs per square inch average steam and vacuum; and the speed, instead of being 220, to be increased to 350 feet per minute—(and many Engines are worked at the speed and pressure here referred to)—the power of the Engine would be increased to 168 horse-power—or to seven times the amount of the "nominal" designation. Though still "nominally" a twenty-four horse Engine, it would, in reality, be an Engine of 168 horse-power. At the speed and pressure above stated, it would indicate that amount. Thus it is by the increase of speed and pressure that Steam Engines are made to exert more power than they were originally calculated for; or at least, more power than the "nominal" designation. Steam Engines are now made much stronger for the same

* This term is here used as in general parlance: not that there is POWER in vacuum; but to make the rule understood amongst those who use the term, the popular idea is here adopted.

"nominal" power, than in the days of WATT. With all Steam Engines, as the pressure and speed are increased, so is the power increased; but this augmentation of power is not obtained without an increased quantity of steam proportionate to the increased pressure, except where steam is used expansively. It will therefore be apparent that the term "nominal" horse-power can only be *legitimately* used in the sale or *purchase* of an Engine. On this rule a twenty-four horse Engine means that the cylinder shall be 26 inches diameter, if a Condensing Engine; and in the same proportion for a larger or a smaller Engine; for 22 square inches of area in the piston is one "nominal" horse, if a Condensing Engine. If we multiply the diameter of the cylinder by the diameter, and divide by 28, the product will be the number of "nominal" horse-power.

EXAMPLE.

Diameter of Cylinder, 30 inches.

30
30
—
28) 900 (32 horse-power.
84
—
60
56
—
4

The purchaser of a Condensing Engine should have 22 square inches area of piston for each "nominal" horse-power, whatever the speed or pressure. The *real* power exerted can only be ascertained by the *Indicator;* hence the term "indicated horse-power."

This is the standard mode of ascertaining the real power for Condensing Engines, as laid down and established by WATT. It is now universally followed by Engineers. In a case tried at Westminster, where power had been "let by the horse," it was referred to arbitration; and the question arose, "what constitutes a horse-power?" After due enquiry, it was legally established, for the first time, that 33,000lbs raised one foot high per minute is one horse-power, which in the Steam Engine can only be correctly ascertained by the use of the *Indicator.*

Non-condensing, or High-pressure Engines, are calculated for the "nominal" power by the following rule:—Eleven square inches area of piston is one "nominal" horse-power. Multiply the diameter of the cylinder by the diameter, and divide by 14, the quotient will be the number of "nominal" horse-power.

A High-pressure Engine, working with 40lbs steam above atmosphere upon the piston, cut off at one-third the length of the cylinder, and expanding the remainder, the piston travelling 220 feet per minute,

would only exert the power for which it was nominally calculated, independent of friction; but take the same Engine and increase the speed from 220 to 440 feet per minute—which is quite practicable in a Horizontal Engine, if the fly-wheel be not too large—the power of that Engine would then be doubled, less the extra friction; but double the quantity of steam would have been used. The exhaust steam would be thrown away at the termination of the stroke at 3½lbs above the pressure of the atmosphere. Suppose steam were introduced to the same cylinder at 80lbs pressure, and cut off at one-third, and worked expansively, as in the first case, the exhaust steam would be thrown away at 16½lbs above the pressure of the atmosphere, being five and a half times the pressure, or loss, sustained from steam at 40lbs. The power given out would also be less in proportion. Steam at 40lbs would yield 38½ horse-power, whilst steam at 80lbs, and cut off at the same point, would only yield 66½, thus showing that the steam has not been used up. A portion of it is lost, in consequence of not being expanded to its full limit, the lost portion escaping into the atmosphere, exerting a corresponding back pressure upon the piston.

High-pressure Engines work at such varied pressures and speeds, that the *real* power can only be ascertained by the *Indicator;* but the "nominal" power can be calculated by the rules explained above. In the purchase of a High-pressure Engine, the buyer should have eleven square inches area of piston for each "nominal" horse-power, whatever may be the speed or the pressure the Engine can be worked at. One cubic foot of water evaporated per hour is taken to be one "nominal" horse-power, or 1,700 cubic feet of steam, at atmospheric pressure.

TO FIND THE POWER OF A STEAM ENGINE ON THE BASIS OF WATT'S DEFINITION.

As before explained, a HORSE POWER is that amount of moving force which, besides overcoming all friction, will raise 33,000lbs weight one foot high per minute: or any smaller weight a proportionately greater height in the same time.

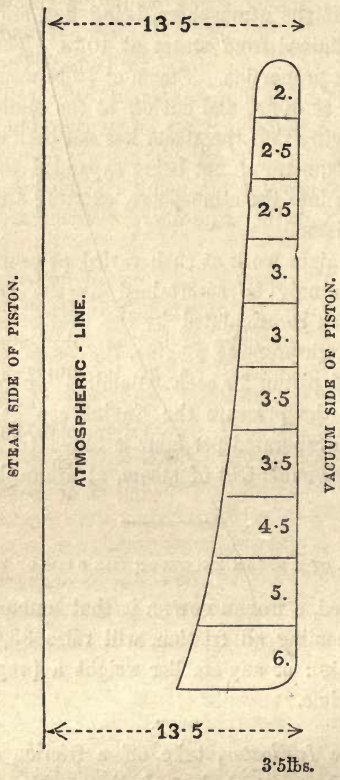
RULE.

By means of the *Indicator*, take off a friction diagram when the Engine has no machinery attached—only the shafting. Divide the length of the figure into ten equal parts. Measure across the centre of each division by the scale of the instrument, or with a common rule. When the number of pounds to the inch has been ascertained, write them down on each division of the diagram; then cast them up, and divide the product by ten. If the figure be divided into more than ten, the product must be divided by the number of the divisions on the diagram. The

quotient will be the average pressure in pounds upon each square inch of the piston—see diagrams Nos. 18 and 19. No. 18 is a friction diagram, and No. 19 a diagram with the Engine loaded with machinery. It may be mentioned that the average friction of Stationary Engines with the shafting, is 3lbs to the square inch, and of Marine Engines $1\frac{1}{2}$lbs to the square inch upon the Engine piston. If a friction diagram cannot be conveniently obtained, the above is the calculation generally

Friction Diagram, No. 18.

Taken from the Top of a Condensing Engine Cylinder.



Average Pressure, 3·5lbs to the square inch upon the piston.

adopted by Engineers, when the available power is required to be known; but where possible, it is best, for accuracy, that a friction diagram should be taken. For example, see Friction Diagram No. 18.

In this diagram, the steam in the cylinder is below the pressure of the atmosphere the full length of the stroke.

EXPLANATION OF THE FIGURING OF DIAGRAMS.

3·5lbs means three pounds and a half upon the square inch. Ten being the whole number, five is half; and all figures from one to ten are in proportion. 2·5, with a dot between, means two and a half pounds; 2·8 means two and eight tenths of a pound; and so on with all figures below ten. 10·5 also means ten and a half pounds to the square inch; so with other numbers; 21·6 means twenty one pounds and six-tenths of a pound.

Our rule for calculating the diagrams from the *Indicator* is given in this simple way, that any person possessing only an indifferent knowledge of figures may understand that rule—for many who were disposed to learn the use of the *Indicator* have been deterred by the use of Algebraic signs in the figuring and calculating of diagrams. These signs are as Greek to a great number of Enginemen, who have not had the benefit of a mathematical education. With the rule here laid down, the comparatively uneducated amongst them can have no difficulty, and the result, for all practical purposes, will be sufficiently accurate.

If the steam upon the piston be below the atmospheric line, the same as in No. 18 Diagram, there will only be one column to add up; but if the steam on the cylinder be above atmospheric pressure, as in No. 19 Diagram, there will be two columns to add up,—one on the steam side, and one on the vacuum side; and these two will have to be added together to get the whole pressure. They may be measured at one measurement when the steam and the vacuum are on the tenth scale, which is the case where the pressure is under 25lbs upon the piston. In the case of a High-pressure Engine, there will only be one column—the steam side; and where there is a back pressure upon the piston, that must be deducted. In a compound High-pressure cylinder, sometimes there is a partial vacuum caused by the steam in the condensing cylinder being below the pressure of the atmosphere; and in some cases, a considerable back pressure is the consequence of the steam on the condensing cylinder being above atmosphere. In the first case, there will be two columns—one for the steam, and one for the vacuum.

RULE TO ASCERTAIN THE POWER REQUIRED TO DRIVE ANY QUANTITY OF MACHINERY: OR THE POWER THE ENGINE IS EXERTING.

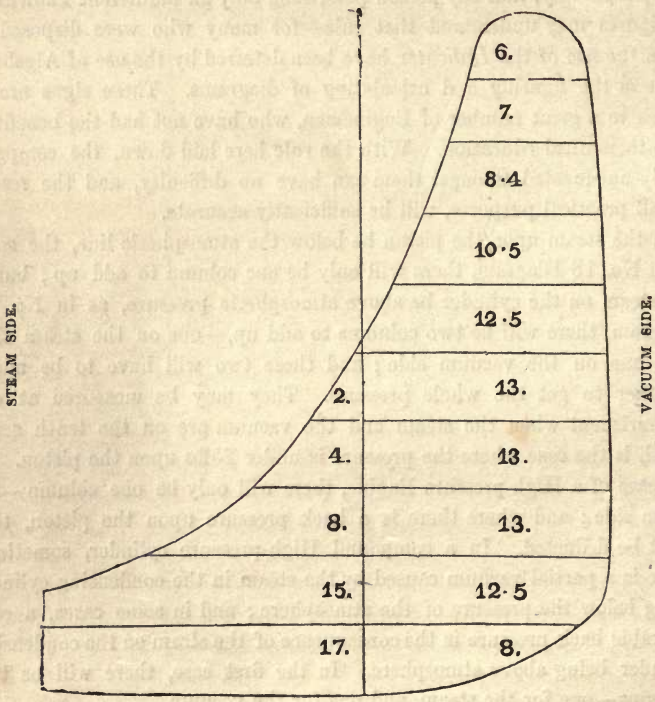
With the *Indicator* take off a diagram when the load is on, or with the machinery in operation you wish to know the power it will take to drive. For example: Diagram No. 19 is taken from a Condensing Engine with the whole of the machinery in motion, belonging to Mr. GOADSBY, of Manchester—that Engine being considered a good example of expanding steam in the cylinder, and also of the setting of valves.

RULE.

The area of the cylinder being given in square inches, multiply by the speed the piston travels in feet per minute, and multiply by the available average pressure in pounds per square inch upon the piston, having deducted the friction of the Engine and shafting, as below: the multiplicand will give the number of available horse-power—independently of the friction of the Engine—when divided by 33,000lbs.

Diagram No. 19,

Taken from the Top of a Condensing Cylinder.



4·6 steam. 10·4 vacuum.

10·4 vacuum.
4·6 steam.

15·0—the average pressure upon the piston.

Deduct friction diagram; or the power required for Engine and shafting ... 3·0lbs.

12·0lbs., the available pressure upon each square inch of the piston.

By giving the number of feet per minute traversed by the piston and the diameter of the cylinder, with a diagram, any person conversant with

the use of the *Indicator* will be able at any time to ascertain the state of his Engine, and what amount of available power it is exerting, or the power for the whole of the machinery the Engine is driving, including shafting and its own friction. It will not be necessary to send for any one to examine the Engine; the diagram will be quite sufficient to explain its condition. For example, examine Diagram No. 19.

Multiply twice the length of the stroke in feet by the number of revolutions per minute; the product will be the speed the piston travelled in feet per minute.

EXAMPLE.

Diameter of cylinder, 32 inches;* speed of piston in feet per minute, 340.

Multiply the cylinder's diameter by the diameter	32 32	
	64 96	
To ascertain the number of square inches, multiply by	1024 ·7854	which is the decimal area of a circle of one inch, 10,000 being one square inch.
	4096 5120 8192 7168	
	804·2496	square inches of the piston. Multiply
	340	by speed of piston—340 feet per minute.
	321699840	
Multiply by the effective pressure upon the piston when the friction of the Engine and shafting has been deducted -	24127488	12lbs., the average available pressure.
	273444·8640	
Divide by 33000)	3281338·3680	take off four figures, being the decimal
	297000 (99	figures of 7854; and the dividend 99 is the number of horse-power.
	311338 297000	
	14338	towards 33000.

By the rule given, we find that this Engine was exerting 99 available horse-power, or 119 horse, including friction of Engine and shafting. At the time the diagram was taken, the Engine was consuming eleven tons of coal per week, including steam for mill, &c., with two boilers of FAIRBAIRN'S patent oval flue, and double fire-box construction. Suppose the eleven tons to be consumed by the Engine when working 60 hours per week, what is the quantity of coal consumed per hour?

* To save the trouble of squaring the diameter, see Table of Circumferences and Area of Circles, given afterwards, which gives the areas of circles per square inch. In this case it will be found to be 804·2496 square inches area.

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EXAMPLE.

Multiply the number of hours	60	
by the horse-power	99	
	540	
	540	
	5940	hours and horse power together.
Reduce the weekly consumption of tons into lbs.	2240lbs., or 1 ton.	
	11—the number of tons per week.	
Divide by the horse-power and the number of hours together	5940) 24640 (	4lbs 2oz. 5dr., the consumption per hour per horse-power. If we deduct the steam for heating the mill, this will reduce the consumption for the Engine under 4lbs per available horse-power, or to 3lbs per hour per horse, for the whole power exerted.
	23760	
Multiply by the number of ounces in the lb.	880	
	16	
	5280	
	880	
Divide by the divisor as before	5940) 14080 (	2oz.
	11880	
Multiply by the number of drachms in the ounce	2200	
	16	
	13200	
	2200	
Divide by the divisor	5940) 35200 (	5 drachms.
	29700	
	5500	towards 1 drachm.

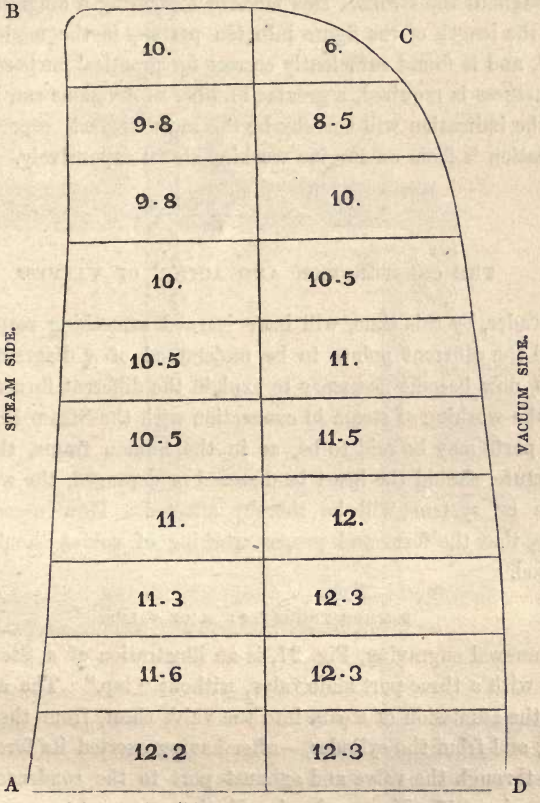
EXPLANATION OF A DIAGRAM.

Diagram No. 20—taken from the top of the cylinder of a Beam Engine. The steam corner A shows the valve at the commencement of the stroke to be rather too forward. It would be better were it a little later. Then the diagram would be a little rounded at the corner A, thus preventing the steam from pressing too much upon the piston when the crank is at the "plumb centre." The Engine is supposed to be working without expansion. The steam continues to the end of the stroke, as shown at B, nearly at the same pressure the whole length, showing that the valve on the steam side has been open the full length of the stroke. The commencement of the exhaust corner, C, being rounded, shows that the valve is too late. It would be better had the exhaust more "lead :" that is, were the valve on the exhaust side to open a little sooner. This would allow the steam to escape into the condenser earlier, and give more power to the steam at the commencement of the stroke. The termination of the exhaust corner D being square, shows the valve also to be too late

in closing the exhaust. If closed sooner, the Engine would work much better. Should the valve be a D, or a common slide three-port valve, add a little lap to the steam side, and set forward the valve by the eccentric. The valve in that case would not open full port. The exhaust would be opened sooner, and closed sooner, which is required. It

Diagram No. 20.

Taken from a Beam Engine with D *Valves without Lap, from the Top of the Cylinder.*



Pressure of Steam, 10·67lbs above Atmosphere.

10·64lbs vacuum.
10·67lbs pressure of Steam.

21·31lbs average pressure of Steam upon the piston.

would then show a rounding at the corner D in proportion to the distance the valve had been moved forward. (See Diagram No. 19, which shows the exhaust closed sooner, as explained.) If the valves are of the kind known as the tappit, they can be regulated independently of each other by the moving of the tappits.

The diagram being divided into ten equal parts, and each measured by the scale, and figured as shown, the average pressure of the steam above atmosphere, and the amount of vacuum, when added together, will show the average pressure upon the piston at each stroke. The average pressure as shown in the example is 21·31lbs per square inch upon the piston. The bottom, or under side, of the piston should be indicated, and the average of the top and bottom taken for the mean pressure per square inch throughout the stroke. This mode of measuring a diagram—viz., by dividing the length of the figure into ten parts,—is the mode generally practised, and is found sufficiently correct for practical purposes. Where great exactness is required, a greater number of divisions can be resorted to, and the indication will thereby be the more correct, especially when the indication is from an Engine working steam expansively.

THE CONSTRUCTION AND ACTION OF VALVES.

THE reader, by this time, will have learned something respecting the form and the different points to be understood of a diagram. It has, therefore, now become necessary to explain the different forms of valves used in the working of steam in connection with the Steam Engine; and as these parts may be said to be, as in the human frame, the heart of the structure, should the heart be diseased or deranged, the whole of the structure or system will be thereby affected. How necessary is it, therefore, that the form and proper working of valves should be fully understood.

COMMON THREE-PORT SLIDE VALVE.

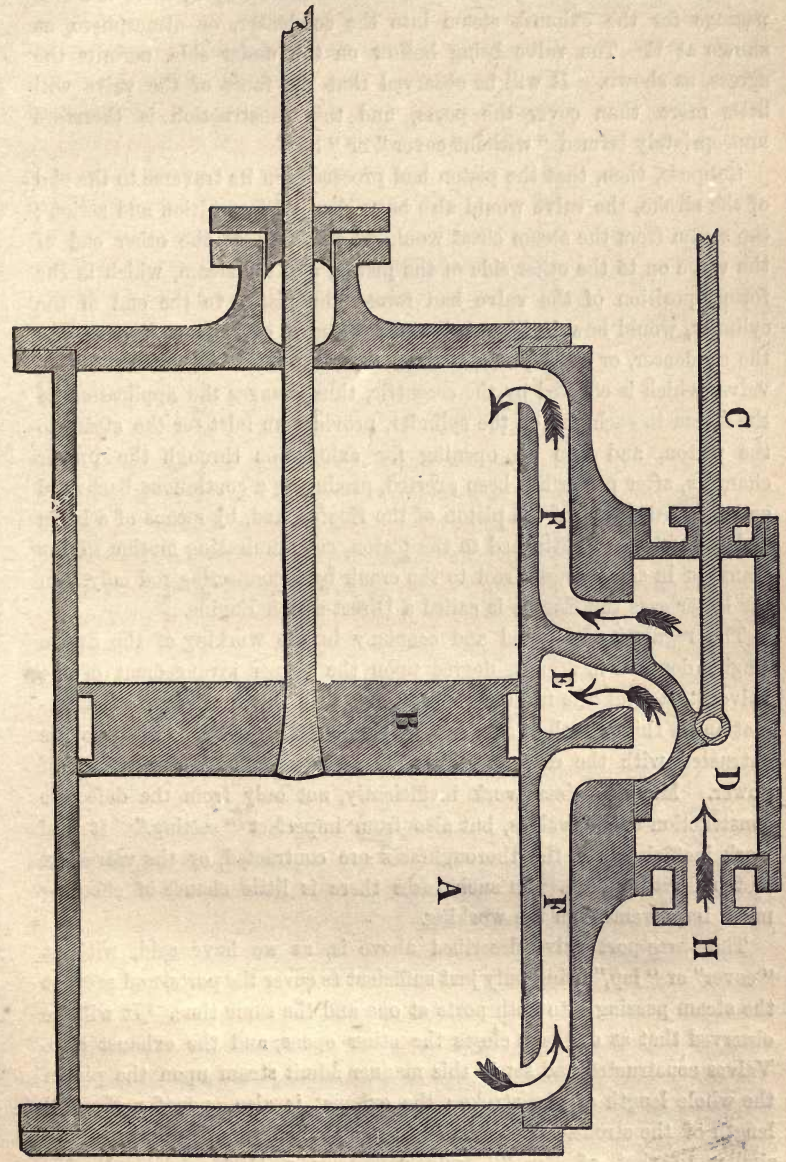
The annexed engraving, Fig. 21, is an illustration of a Steam Engine cylinder with a three-port slide valve, without "lap." The arrow at H denotes the admission of steam into the valve chest, from thence to the cylinder, and from the cylinder,—after having exerted its force upon the piston—through the valve and exhaust port to the condenser—or into the atmosphere, if a Non-condensing Engine.

On reference to the illustration it will be seen that the steam and exhaust ports are of equal dimensions; F F are the thoroughfares to each end of the cylinder, and E the thoroughfare for the exhaust steam to escape into the condenser or into the atmosphere, as the case may be.

The valve, as now shown, is attached to the rod C, the traverse being attained by the usual means. When the Engine makes one-half of a revolution, or one stroke up or down, the valve changes its position accordingly.

Figure No. 21.

CYLINDER AND SLIDE VALVE.



As before observed, the arrow H denotes the steam passage from the Boiler to the valve chest D. As the valve is shown, there is a direct opening for the steam through the steam-way F, to act upon the piston B; and on the under side A, through the exhaust way F, there is a free passage for the exhaust steam into the condenser, or atmosphere, as shown at E. The valve being hollow on the under side, permits the egress, as shown. It will be observed that the faces of the valve will little more than cover the ports, and this construction is therefore appropriately termed "without cover" or "lap."

Suppose, then, that the piston had proceeded in its traverse to the end of the stroke, the valve would also have changed in position and action; the steam from the steam chest would be admitted at the other end of the valve on to the other side of the piston, and the steam, which in the former position of the valve had forced the piston to the end of the cylinder, would now be liberated, and allowed to exhaust or depart into the condenser, or atmosphere, through E. The traversing motion of the valve, which is effected by the eccentric, thus changes the application of the steam to each end of the cylinder, provides an inlet for the steam to the piston, and also an opening for exhaustion through the proper channels, after power has been exerted, producing a continuous backward and forward action of the piston of the Engine, and, by means of a beam and connecting-rod attached to the piston, communicating motion to the crank, or in some cases direct to the crank by a connecting-rod only. In the latter case the Engine is called a Direct-action Engine.

The regularity of speed and economy in the working of the Steam Engine depends in a great degree upon the proper arrangement of the valves. It is of the utmost consequence that full and complete information on this branch of the subject should be acquired by all who are entrusted with the care and direction of this valuable instrument of power. Many Engines work inefficiently, not only from the defective construction of the valves, but also from imperfect "setting." It will work inefficiently if the thoroughfares are contracted, or the valve-box be too short, or both. In such cases there is little chance of effecting much improvement in the working.

The three-port valve described above is, as we have said, without "cover" or "lap," being only just sufficient to cover the ports, and prevent the steam passing into both ports at one and the same time. It will be observed that as one port closes the other opens, and the exhaust also. Valves constructed and set in this manner admit steam upon the piston the whole length of the stroke; the exhaust is also open for the full length of the stroke. Were an *Indicator* applied, the diagram would be similar to that of No. 22, which is from a High-pressure Engine

working without expansion—the exhaust neither opening nor closing before the piston has traversed its full length. The working and economy of this Engine would be greatly enhanced by "lapping" the valve, as in Fig. 23—the steam being used expansively. The steam port has been

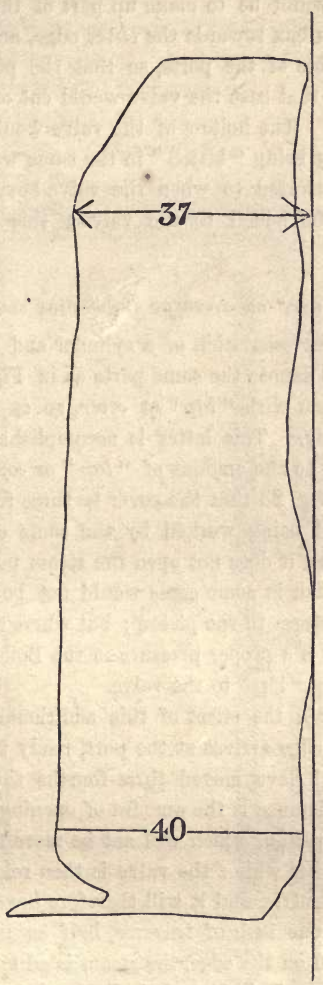


Diagram No. 22.
From a High-pressure or Non-condensing Engine.

closed earlier, therefore the steam has been cut off before the termination of the stroke. The steam already in the cylinder would then expand and force the piston forward the remainder of the stroke. To produce the same power, however, a greater pressure of steam would be required on

the piston at the commencement of the stroke; but as the Boiler in this instance is already pressed up to the limit of safety, the Engine necessarily consumes a greater quantity of fuel than it would if the steam could be worked expansively.

To enable this valve to cut off earlier and work expansively, without adding "lap," would be to make up part of the thoroughfares at each end of the valve-box towards the outer edge, and cut away some of the metal in the inside of the ports, so that the ports would not be much contracted. In that case the valve would cut off the steam the same as if it had "lap." The hollow of the valve would require to be proportionately less, by being "bitted" in the same way as the thoroughfares. This mode is resorted to when the valve-box is too short, and where "lap" cannot be added to the valve; this is called "lapping the thoroughfares."

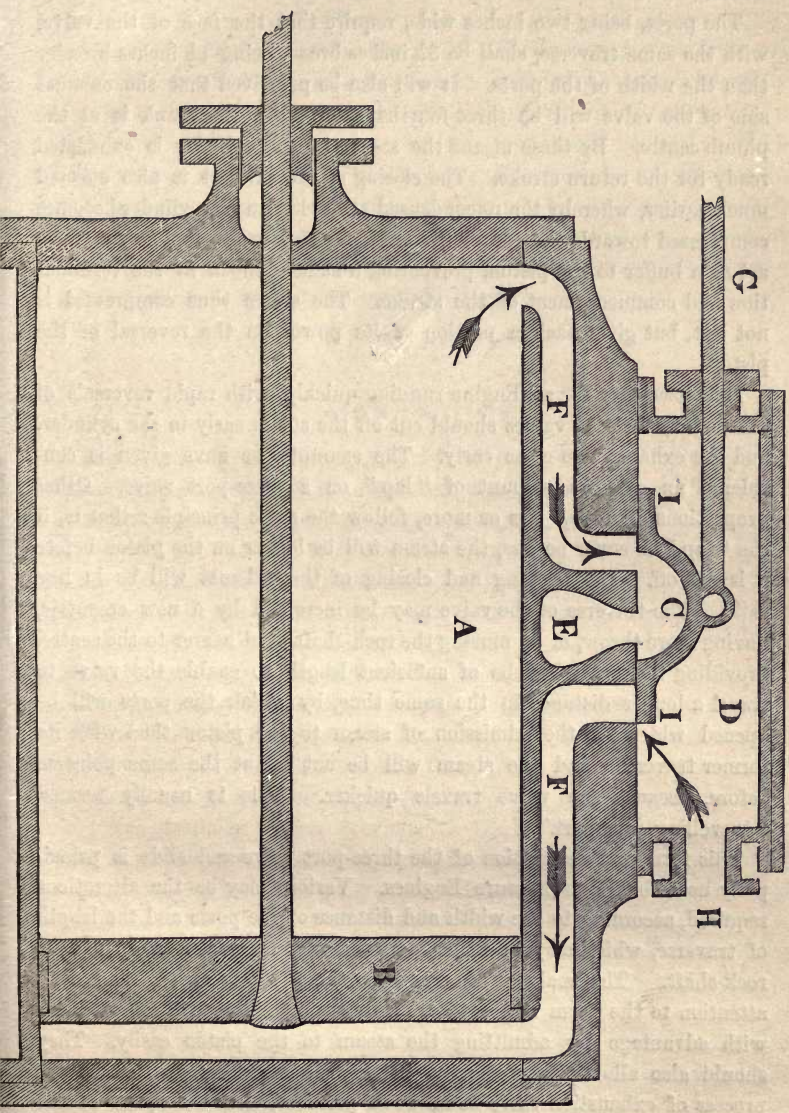
"LAP," OR COVER OF THREE-PORT SLIDE VALVES.

Fig. 23 is a representation of a cylinder and a three-port slide valve. The same letters denote the same parts as in Fig. 21. In this instance the valve is shown with "*lap*" or *cover*, so as to cut off the steam to work expansively. This latter is accomplished to a greater or less degree according to the amount of "*lap*" or *cover* of the valve. It will be observed in Fig. 23 that the cover is three-fourths broader than the steam ports, and being worked by the same eccentric, with the same length of traverse, it does not open the steam port more than one-fourth of its width, which in some cases would not be sufficient to admit the full pressure of steam to the piston; but where the ports are of sufficient width, and there is a proper pressure in the Boiler, no difficulty is experienced by adding "lap" to the valve.

Let us ascertain the effect of this additional breadth of valve face. When the valve edge arrives at the port, ready to admit the steam upon the piston, it will have moved three-fourths the length of its traverse. The remaining distance is the amount of opening given for the admission of steam to the piston, which will not be more than half an inch, if the ports be two inches wide: the valve is then reversed by the motion or throw of the eccentric, and it will therefore have opened and closed the steam port with one inch of traverse, half an inch each way. As this valve is V shaped on the edge, the steam is admitted to the piston easily, and cut off easily. This is technically termed "easy steaming." Were the *Indicator* applied, the diagram would be similar to Diagram No. 24. At the termination of the piston's descent, the steam is fully exhausted ready for the return stroke. This is called "lead of the exhaust." The full length of the traverse of the valve is four inches for one revolution

Figure No. 23.

CYLINDER AND SLIDE VALVE, WITH "LAP."



of the Engine. This arrangement cuts off the steam at about one-fourth the length of the stroke, the remainder of the stroke being worked by the expansibility of the steam. Each end of the valve is of the same width.

The ports, being two inches wide, require that the face of the valve, with the same traverse, shall be $3\frac{1}{2}$ inches broad, being $1\frac{1}{2}$ inches broader than the width of the ports. It will also be perceived that the exhaust side of the valve will be three-fourths open when the crank is at the plumb centre. By these means the steam in the cylinder is exhausted ready for the return stroke. The closing of the exhaust is also effected much earlier, whereby the uncondensed steam left in the cylinder becomes compressed towards the end of the stroke. This in practice is found to act as a buffer to the piston, preventing a sudden shock at the termination and commencement of the stroke. The steam thus compressed is not lost, but gives back a portion of its power on the reversal of the piston.

It is necessary for an Engine running quickly, with rapid reversals of the piston, that the valves should cut off the steam early in the cylinder, and the exhaust also close early. The example we have given is considered an extreme amount of "lap" on a three-port valve. Other proportions of "lap," less or more, follow the same principle: that is, if the "lap" or cover be less, the steam will be longer on the piston before it is cut off. The opening and closing of the exhaust will be in like ratio. The traverse of the valve may be increased by a new eccentric, having more throw, or by moving the rock-shaft stud nearer to the centre, providing the valve-box be of sufficient length to enable the valve to travel a longer distance in the same time, by which the ports will be opened wider for the admission of steam to the piston than with its former traverse; and the steam will be cut off at the same point as before, because the valve travels quicker. This is usually termed "travelling over port."

This form and description of the three-port valve and slide is principally used for High-pressure Engines. Various may be the alterations required, according to the width and distance of the ports and the length of traverse, which may be either increased or decreased, if worked by a rock-shaft. The makers of small portable Engines will find that attention to the form and setting of three-port valves will be attended with advantage by admitting the steam to the piston easily. They should also allow plenty of room in the thoroughfares, so that in the process of exhaustion there be no back pressure, that the speed of the Engine may be increased when more power is required. At the Royal Agricultural Show at Leeds, 1861, there was observable a general defect

in this class of Engines—want of speed of the piston, which could not well be increased on account of the fly-wheel being too large. Defects such as these are serious drawbacks upon High-pressure Portable Engines, or to Engines of any other form. Attention to *balancing* the working parts of an Engine steadies the working, and requires less matter to be put and kept in motion to equalise the speed. If the pressure were increased from 45lbs to 70 or 80lbs to the square inch (which might be safely effected with small Boilers of the Portable class), the steam would be used more expansively : consequently, less fuel would be used, and an increased power obtained. We are aware that there is an objection to high-pressure steam among agriculturalists ; but how that arises it is difficult to understand, seeing that Railway Locomotives work steam at from 100lbs to 150lbs pressure to the square inch with perfect safety—exerting great power, and occupying little space.

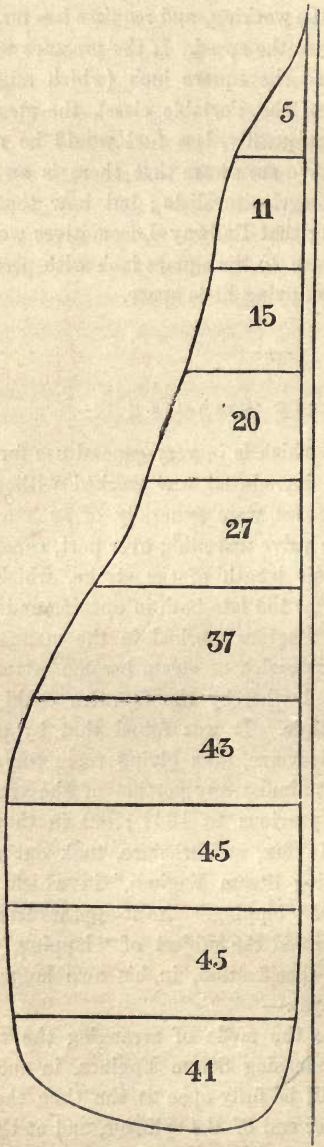
THE D SLIDE VALVE.

This description of valve, which is in very general use for Condensing Steam Engines, when first introduced was worked without "lap," or extra cover, and the valve-boxes were generally of such a length that they would not admit of the valve travelling over port, consequently, the steam was admitted the whole length of the stroke, which caused the exhaust side of the valve to be too late both in opening and closing. For a long period Low-pressure Engines worked in the manner described ; but as the property of the expansion of steam became better understood, various methods were adopted whereby the D valve could be made to work on the expansive principle. It was found that by enlarging the valve-box to allow of more traverse, thus giving room for extra "lap," the steam could be cut off at almost any portion of the traverse. This fact was partially known previous to 1841 ; but in that year a Mr. Bould, cotton spinner, of Halifax, in Yorkshire, took out a patent for "Improvements in Condensing Steam Engines," in which he describes the D valve and the mode of "lapping." As it appears from his specification that he clearly understood the subject of "lapping," and setting valves, extracts from that specification, in his own language, will be found of advantage. He says :—

"My invention relates to the mode of arranging the valves (which slide over the ports) of Condensing Steam Engines, in such a manner that the exhaustion port shall be fully open at the time the piston has completed its stroke, at either end of the cylinder, and at the same time allow of the steam being worked expansively by means of the same

Diagram No. 24.

From a High-pressure or Non-condensing Engine, with "lap" on the Valve, and V *on the edge.*



The space between the atmospheric line and the pressure line is the amount of back pressure, about 2½lbs upon the square inch on the piston, caused by the thoroughfares being too small, or the exhaust pipe having many elbows and obstructions to the free egress of the steam.

valves. * * * In constructing and applying valves to Condensing Steam Engines, the valves of which are worked by eccentrics, it is usual to form the valves of such dimensions that they will only just cover the ports or openings into the cylinder, or only very slightly exceed the dimensions of the port; hence, when the valves are moved, the ports are simultaneously, or nearly simultaneously, opened and closed. * * * By enlarging the size of the slides so that they will be much larger (at least twice as large as the ports they work over), the induction valve may remain closed during a considerable length of movement of the valves; hence it may be closed at any desired part of the stroke of the Engine, and the exhaustion valve remain open to the condenser; and what is also very important, the exhaustion valve may be fully open at the termination of the stroke at either end of the cylinder, so that a good vacuum may at the commencement of the stroke be obtained, and consequently at the time the induction port is open for the flow of steam.

"Fig. 25 represents a diagram of a steam cylinder and valves, and also the eccentrics and parts which work the valves. In Fig. 25 the valves are shown in the position they would be at the termination of the stroke at the upper end of the cylinder; and it will be seen that the exhaustion valve has passed away from the exhaustion port, and the induction or steam valve has partially opened the induction port. * * That is not necessary; but if desired, it will be evident to the Engineer that that might be done either by increasing the throw of the eccentric, or by shortening the lever e,[1] to which the eccentric rod is attached.

"Fig. 26 shows a section of a steam cylinder and valves, and the lever which works them, the eccentric which gives motion to the lever not being shown—the valves in this figure being in the reverse position to that shown in Fig. 25. The valves $a\ a$ are made of such length as to be equal to three times the opening of the ports; and it will be seen by tracing the movement which will take place in the parts of Fig. 25, that when the stroke in the upward direction has been completed, and the steam or induction valve opened to the required extent, and steam admitted above the piston, the steam or induction valve will be closed by the time the piston has moved about one-third of its stroke; but this may be varied, and the exhaustion port will remain open, and the movement of the eccentric, and the parts actuated thereby, will, near the end of the stroke, close the exhaustion port at the upper end of the cylinder, and bring the parts into the positions shown in Fig. 26; and it will also be seen that these effects will be consequent on the enlargement of the valves in respect to the ports over which they work, and the extent of movement given to the valves, whereby one or other of the valves can be moved for a considerable length whilst over its port, without uncovering

NOTE.—Those passages marked *s* are the openings of the pipe which convey the steam from the upper to the lower nozzle or valve chest, and the passages marked *v* are the openings of the pipe which convey the steam to the condenser.

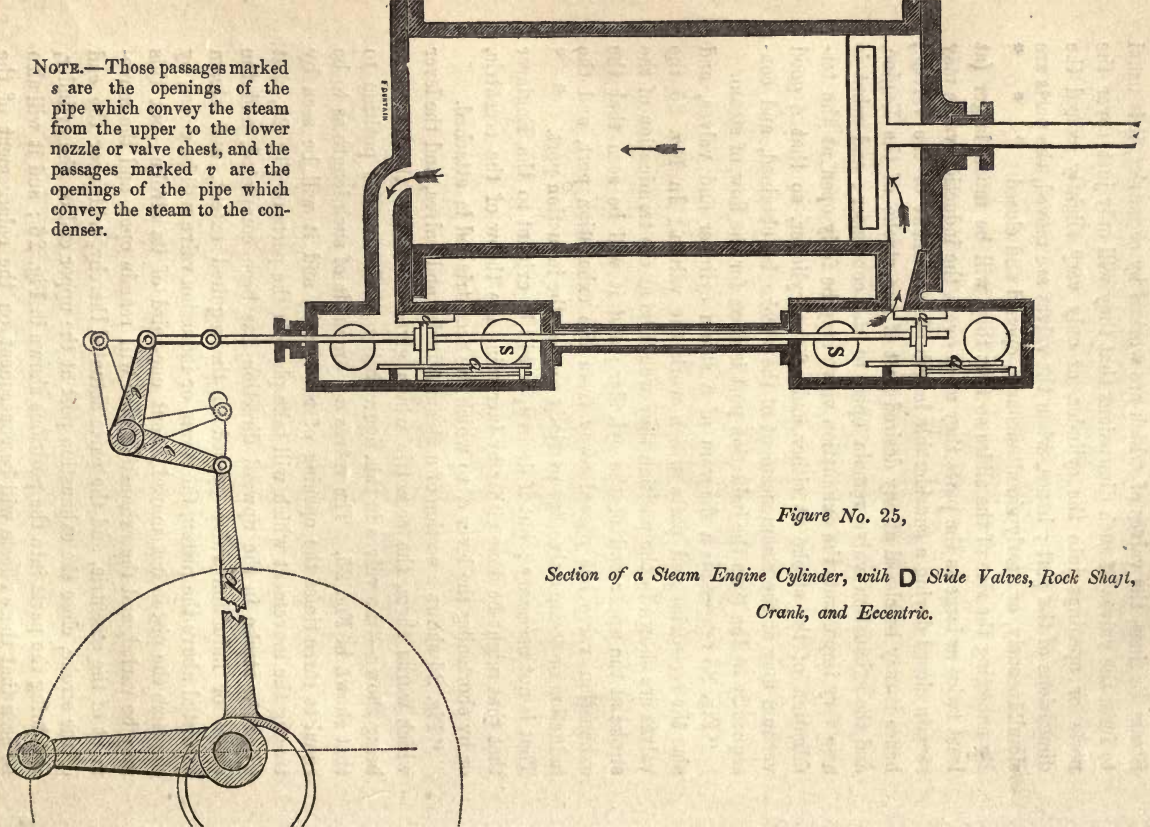
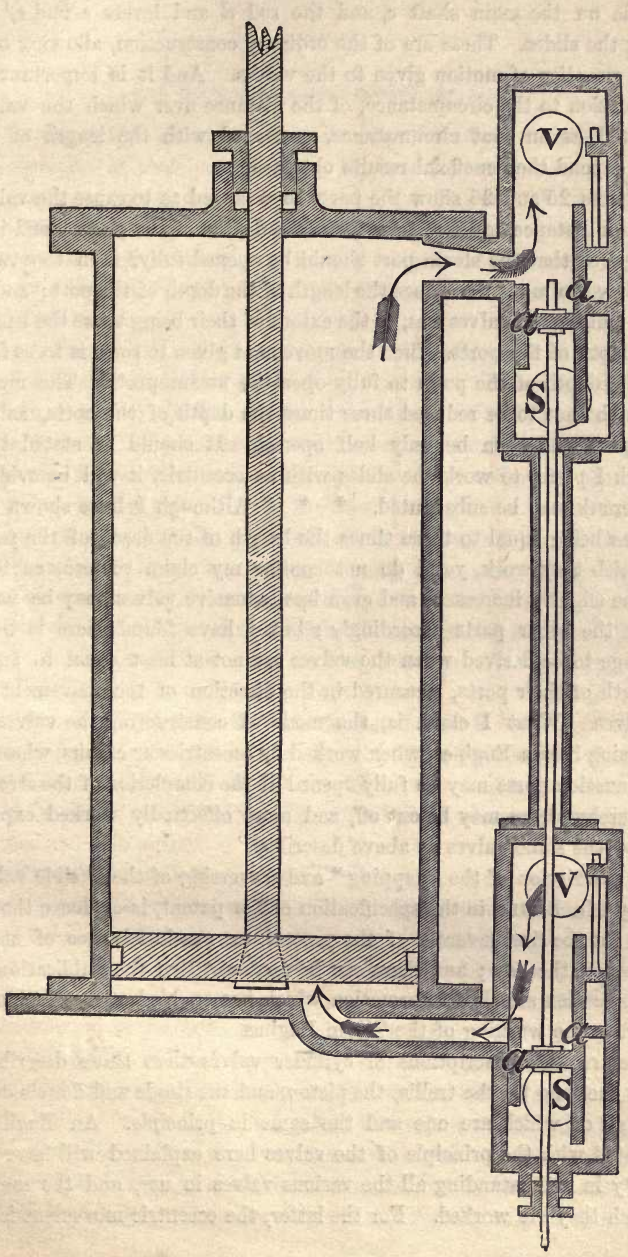


Figure No. 25,

Section of a Steam Engine Cylinder, with D *Slide Valves, Rock Shaft, Crank, and Eccentric.*

Figure No. 26.

An Enlarged Section of Steam Engine Cylinder with D *Valves.*



that port, allowing the exhaustion port to be fully open at the time of completing the stroke at either end of the cylinder. At Fig. 25, *b* is the eccentric on the main shaft *c*, and the rod *d* and levers *e* and *e*,[1] for moving the slides. These are of the ordinary construction, allowing only for the quantity of motion given to the valves. And it is important to call attention to the circumstance, of the distance over which the valves are moved, as on that circumstance, combined with the length of the valves, depend the beneficial results obtained.

"Figures 25 and 26 show the parts so arranged as to cause the valves to move a distance equal to four times the depths of the ports; and if it were desired that the steam port should be opened fully, then the valve would have to move five times the length of the depth of the port; and in case of making the valves less, to the extent of their being twice the length of the depth of the ports. Then the movement given to them is to be four times the depth of the ports to fully open the steam ports. The movement ought not to be reduced three times the depth of the ports, as the steam port will then be only half opened. It should be stated that although I prefer to work the slides with an eccentric, it will be evident that a crank may be substituted. * * * Although I have shown the valves as being equal to three times the length of the depth of the ports over which they work, yet I do not confine my claim thereto, as they might be slightly increased, and even less extensive valves may be used, varying the other parts accordingly; but I have found there is little advantage to be derived when the valves are not at least equal to twice the length of their ports, measured in the direction of the movement of the valves. What I claim is, the mode of constructing the valves of Condensing Steam Engines, when worked by eccentrics or cranks, whereby the exhaustion ports may be fully opened at the completion of the stroke, and whereby steam may be cut off, and more effectually worked expansively by the same valves as above described."

This description of the "lapping" and traversing of the D slide valve, given by Mr. Bould in the specification of his patent, is evidence that if he was not the first inventor of the process, he was in advance of many Engineers of the day; and there can be no doubt that the publication of his specification supplied information which has enabled other Engineers to improve the working of the Steam Engine.

There are other descriptions of cylinder valves than those described, such as the long D, the trellis, the piston, and the single and double drop valves, all of which are one and the same in principle. An Engineer acquainted with the principle of the valves here explained will have no difficulty in understanding all the various valves in use, and the modes by which they are worked. For the latter, the eccentric movement is in

most general use; but there are also the movements of the cam, the tappit, the crank, and the lever.

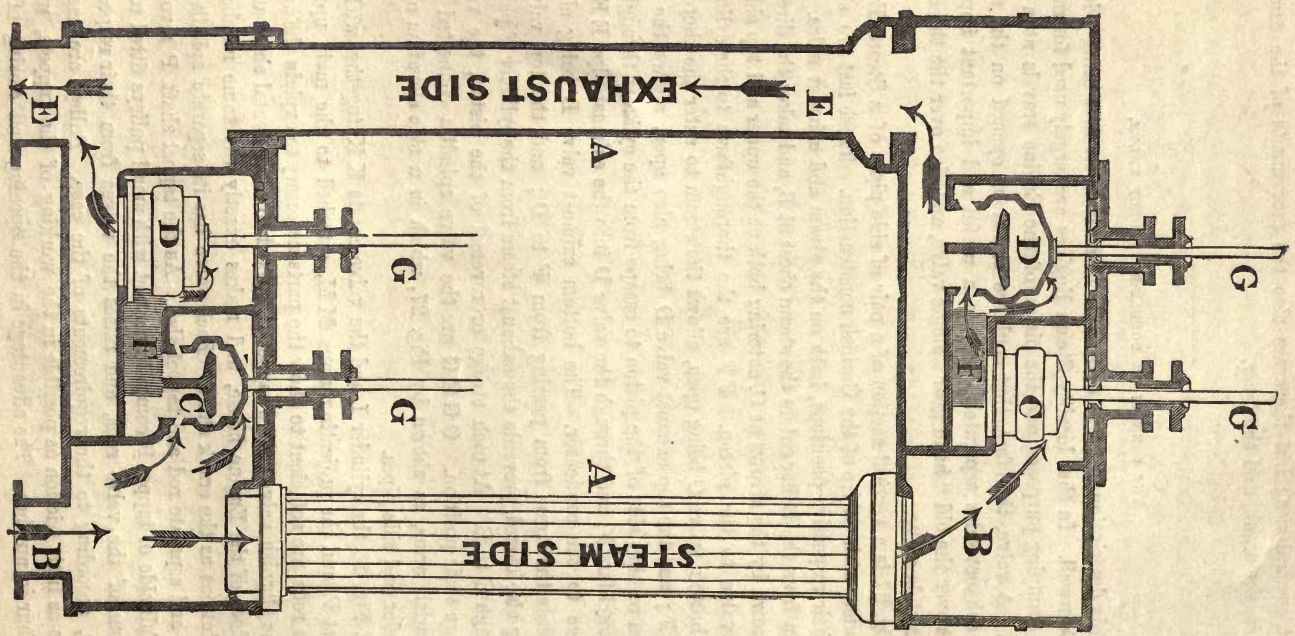
THE CORNISH OR DOUBLE-BEAT DROP VALVE.

This description of valve derives its name from its first being adopted in Cornwall. In that locality Steam Engines are largely used for mining and pumping purposes, and the piston of the Engine travels at a slow rate. A valve, therefore, that could be closed or opened on the steam and exhaust sides separately, became a useful and important improvement over the old "hand gear" single valve, and also over the three-port or D slide valve.

Fig. 27 is a vertical section of a pair of side pipes of a Steam Engine cylinder, with valves of the Cornish construction. These last are shown in their respective positions, both on the steam and exhaust sides. The steam from the Boiler enters the steam chest at B, and takes the direction as shown by the arrows at C, entering both at the under and top sides of the valve to the piston. F F are the thoroughfares to the cylinders. The bottom valve C being open, allows the steam to enter the thoroughfare F; and the top exhaust valve D being also open, allows the used steam on that side of the piston to escape from the cylinder through the thoroughfare F, and through the valve D into the exhaust pipe E E, and thence to the condenser. The bottom exhaust valve D being closed, prevents the steam from passing from F to D; and the top valve C being also closed, prevents the exhaust steam from the cylinder F passing through C to B. At each stroke or reversal of the piston, the valves change their position. G G G G are the valve spindles connected to a rod with arms, as shown by Fig. 27, which is a side elevation of the cylinder and side pipes.

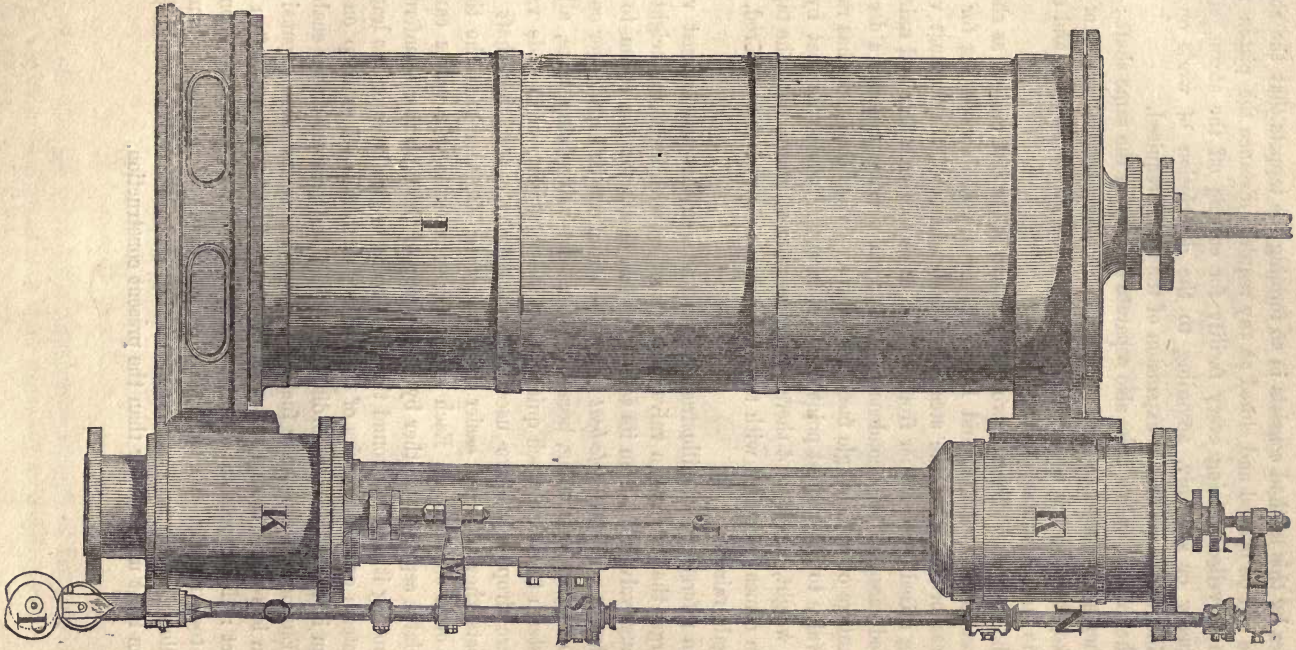
In Fig. 28 the cylinder I, and the valve chests K K, together with the tappet P, and the projecting arms M M, attached to the main upright valve rods, are sufficient to show the parts necessary to explain the action of the Cornish valve. The tappet P is fixed to a horizontal shaft under the floor of the Engine house, and makes exactly the same number of revolutions as the crank shaft. Each valve has its separate spindle and arm, and separate rod and tappet also. As the tappet shaft P revolves, the full side of tappet P comes in contact with small pulleys fitted to the bottom of the valve rods, and raises the valves from their respective seats, according to the requirements of the case. Pulleys are used to cause as little friction as possible in the working of the tappets, which are four in number. The advantage in the opening and closing of the

Figure No. 27.



Section of a Steam Engine Cylinder Side Pipes, with Cornish Drop Valves.

Figure No. 28.



Side View of Cylinder and Side Pipes, with Cornish Valves and Revolving Tappets.

valves by this method consists in so forming the tappets that the steam valve can be opened and closed at any required distance the piston may have travelled—giving every facility for cutting off the steam, either gradually or suddenly, according to the description of work on the Engine, or the amount of expansion of the steam required.

The exhaust valves have also separate tappets on the same shaft; and as they are required to keep open the valve nearly the full length of the stroke, the tappet is so formed as to cause the valves to open and close at the most advantageous times.

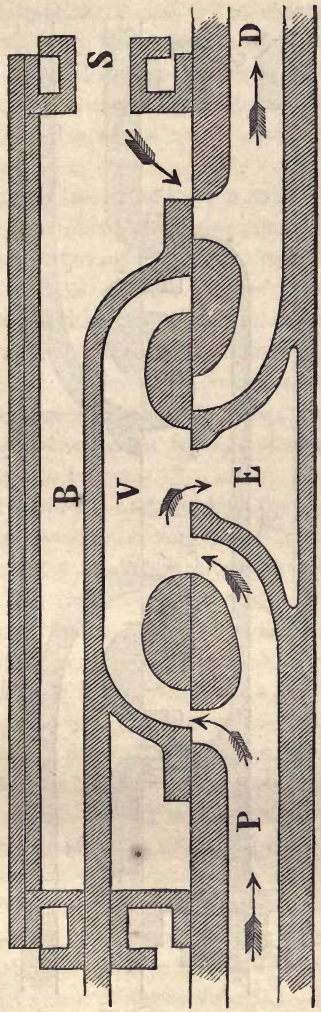
The Cornish Valve has two faces, or two inlets and outlets, as shown by section of valve C and D, which gives a double opening for the ingress or egress of the steam. It also admits of the exhaust valve being raised much higher from its seat, so as to give a free and uninterrupted passage to the condenser. This form of valve possesses a decided advantage over the single faced drop valve. When the tappet has raised the valve to the highest point required, it again falls to its seat by its own weight, and is kept there by the pressure of steam, until the tappet again comes in contact with the pulley at the foot of the valve-rod, and is again raised.

On reference to the illustration it will be seen that the exhaust valve is larger than the steam valve, which, coupled with the extra height the exhaust valve rises from its seat, gives free egress for the steam to the condenser. With *double-beat* valves the steam can be kept longer on the piston before exhausting, because the exhaust valve being large, allows the steam to escape much quicker than the three-port, or D slide valve. Where drop valves are used, and worked by a revolving shaft and tappets, they are much easier to get at by the Engineer than the three-port or D slide valve. Each tappet being separate, the valves can be regulated separately, either by the shaping of the tappet's circumference, or moving it partially round the shaft, so as to give more or less lead on the steam or exhaust sides of the stroke; or to take off or keep on the steam in the cylinder, according to the load and pressure: thus enabling the Engineer to economise fuel by working his steam more expansively when less power is required. In this form of valve there is often one defect: the tappets are so formed as to allow the valve to drop upon its seat too suddenly, causing much wear and noise. Were the tappets made to allow the valves to be steadied on their seats, the valves would keep steam-tight much longer than the present construction.

IMPROVED SLIDE VALVE, WITH DOUBLE EXHAUST.

Fig. No. 29 is a representation of the Improved Slide Valve, with double exhaust; S and B are the valve chest, V the slide valve, P and D the steam-ways to each end of the cylinder, and E the exhaust. It will

Figure No. 29.

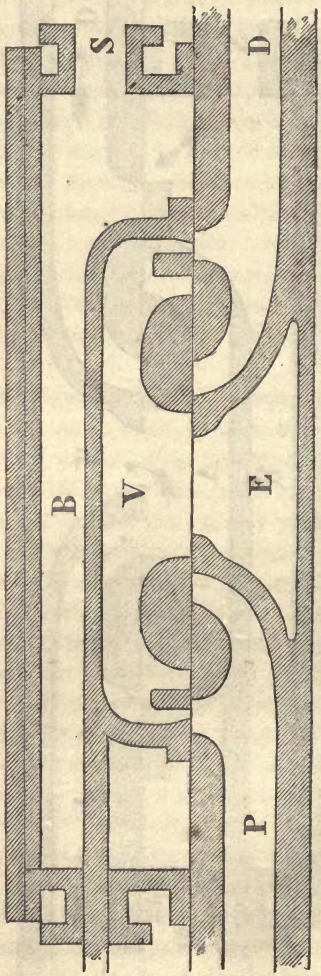


be perceived that the valve has a considerable amount of lap, which will cut off the steam early, and thus work expansively, proportionate to the amount of lap.

Fig. 30 is another representation of the same description of valve, except with less lap. The same Figure denotes the same parts as Fig. 29.

It is well known that when "lap" is applied to the ordinary slide

Figure No. 30.



valve, the exhaust interferes too early with the action of the Engine, and allows the steam to escape to the condenser or atmosphere before it has had full opportunity of giving out to the piston the whole of its impelling

force. This defect prevents that economy of fuel which would otherwise be realised from the working of steam expansively.

With the slide valve of the ordinary construction, the exhaust has to be set forward exactly in proportion to the amount of "lap" applied over the other thoroughfare, where "lap" is sufficient to cut off the steam so as to work with any considerable degree of expansion, and thus secure a reduction in the consumption of coal. The exhaust interferes in the manner above pointed out. To remedy this, many Engineers have abandoned both the slide valve and the eccentric, and have adopted other forms of valves, of a costly and complicated description; but these complicated constructions require too much nicety of management, and are liable to derangement.

On reference to Figures No. 29 and 30, it will be observed that the steam passages are changed, both in the side pipes and in the slide valve, and that they have such a form given to them as to enable "lap" to be conveniently applied on the exhaust side of the valve without any hindrance to the speed of exhausting the steam. It will also be perceived that two openings are provided for the steam to exhaust through, by which a quick exhaust is accomplished with half the traverse that is required by the old arrangement; and that, too, without such an enormous amount of lead being given to the exhaust in advance of the termination of the piston's traverse.

By reducing the traverse one-half, one half the amount of "lap" only is required. In the improved valve very little "lap" on the exhaust side will be sufficient to confine the steam longer in the cylinder, so as to enable it to give out the whole of its expansive force upon the piston before it is discharged to the condenser or to the atmosphere. The old form of slide valve has been repeatedly tried to accomplish this, with "lap" on the exhaust side, but in consequence of its long traverse, the amount of "lap" required was so great as to choke up the thoroughfares, and thus cripple the power of the Engine.

On examining Figure No. 30, an opening will be perceived, sunk in the crossbar. This opening is provided specially for that small portion of steam to escape which is left in the cylinder when the piston approaches the termination of the stroke. A small opening such as this is found to be necessary for the exhaust not wholly to close until the crank has arrived near the dead centre, in order to prevent those expensive *breakdowns*, which have been too frequently the result of the exhaust closing too early, otherwise it would be difficult to start the Engine.

The short traverse of the valve, under the new arrangement, has the advantage of admitting the steam on the piston slowly at the commencement of the stroke, and that, too, without a V being provided for the

purpose. The steam can therefore be cut off much sooner, and the expansive principle thus becomes more practically accomplished with slide valves of this construction.

In practice, it is found that with a Boiler pressure of 30lbs, an opening of a quarter of a square inch in area per nominal horse is sufficient for the valve to open to admit steam to the piston; that a Boiler pressure of 15lbs requires one-third of a square inch; and that a Boiler pressure of 7lbs requires an opening of half a square inch for each nominal horse. The exhaust requires one square inch area, or upwards, for each nominal horse. Where the opening of the exhaust is less than this, the working of the Engine will be crippled, and a loss of fuel the consequence.

For Locomotive Engines this form of valve will be of considerable advantage, as the cut-off can be effected easily, and the exhaust opened quickly, allowing the steam to depart with a greater speed than the ordinary arrangement.

ON THE "SETTING" OF STEAM ENGINE VALVES.

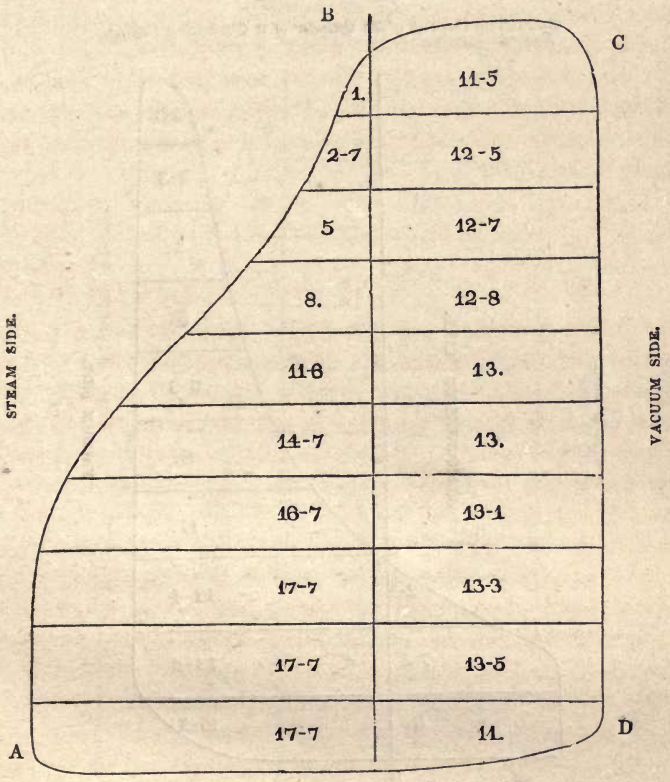
The proper "setting" of Steam Engine valves is perhaps the most important duty the Engineer has to undertake, involving nicety of calculation and mechanical accuracy, that the strain upon the Engine may be equal throughout the whole length of the stroke. With the assistance of the *Indicator*, the Engineer will be enabled to regulate his valves, and employ the motive power to the best advantage, according to the varying circumstances arising from the peculiar construction of the Engine, the pressure of the steam, or the amount of work the Engine may have to perform. From the fact that these circumstances of construction, pressure, and work of different Engines do vary, it will at once be apparent that one uniform rule for valve-setting cannot be laid down. A perusal of the foregoing pages will have shown, by several of the diagrams and the accompanying comments, that various alterations in the setting of valves were required to improve and perfect the working of the different Engines. Fuel is saved, and power increased—or, in other words, the power generated is rendered most available, when the valves are set, so as to "beat" at the proper time. This setting will, for the reasons before assigned, necessarily have to be regulated and modified according to the pressure of the steam, the size of the steam ports, and the different degrees of expansion. For example, see Diagram No. 31.

The corner A is the steam side of the piston. When the crank is at the "plumb-centre" the valve is one-sixteenth of an inch open at the bottom of the V, and this is called one-sixteenth of an inch *lead* on the

steam side. When the piston has travelled one-third the length of the cylinder, the valve has been opened as much as is required, and it is then closed—having cut off the steam at one-third of the stroke, except the V portion, which closes slowly. By the expansive action of the steam, the piston is forced forward the remaining portion of the stroke. When the piston arrives at the bottom of the cylinder, the crank is at the

Diagram No. 31.

Taken from the Top of a Low-pressure Cylinder with D *Valves.*

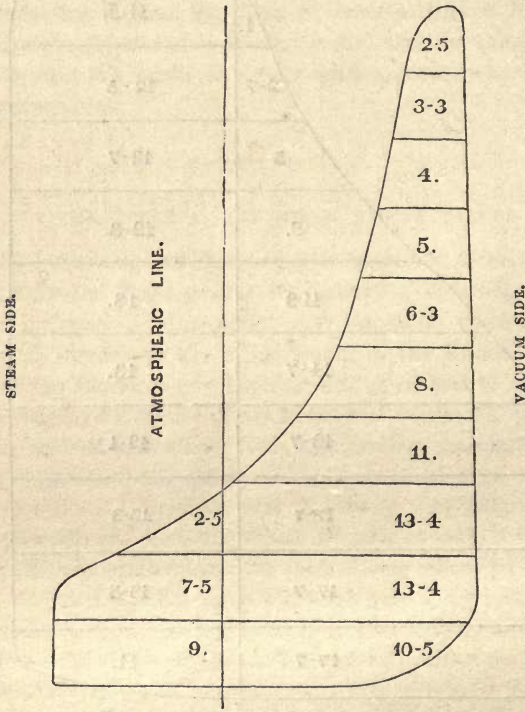


opposite "plumb-centre." The exhaust-valve is then open two-thirds—in some cases fully open, where the thoroughfares are small. This is usually termed "the lead of the exhaust"; the steam having escaped into the condenser, and a vacuum having been formed ready for the return stroke. [See corners B and C.] The exhaust-valve closes when the piston has travelled nine-tenths of the length of the cylinder: and this is called the closing of the exhaust. [See corner D.] The little

steam remaining in the cylinder when the exhaust is closed, is compressed, and performs the office of a buffer—checking the speed of the piston at the termination of the stroke, ready for the return. This is called "cushioning." The Engine works much easier when the exhaust closes before the end of the stroke, more particularly when the piston travels quickly, the steam between the piston and the cylinder top or bottom becoming compressed—care being taken that the amount of compression be not too great, so as not to decrease the power, or strain the Engine.

Diagram No. 32.

Taken from the Top of the Cylinder of a Condensing Engine.



The compressed steam expands at the return stroke—giving out power proportionate to the compression.

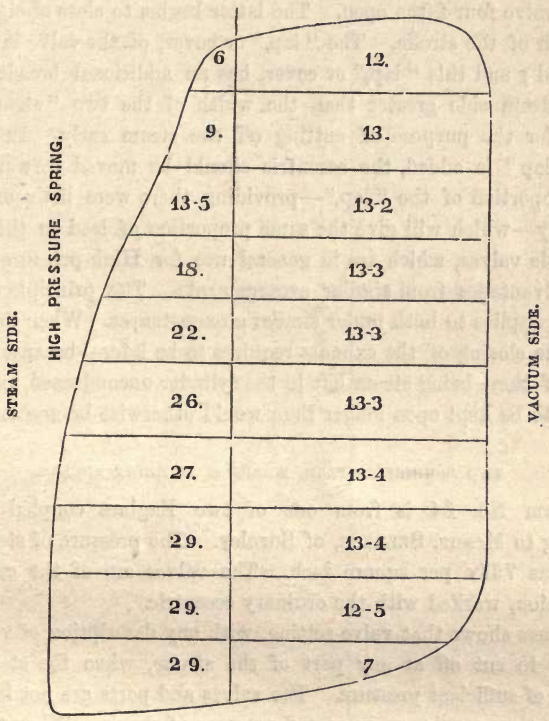
The foregoing description applies to an Engine with D, or slide valves.

Tappet valves may be fixed to cut off the steam and open the exhaust at any required distance the piston may have travelled in the cylinder, by having the tappet made movable, or the faces formed as required. In Diagram No. 32, the valves are tappet valves, and the steam is cut off at

one-seventh the length of the cylinder. The expansive principle can thus be made available for the varying amount of the work required, and showing also that valve-setting must vary as the load on the Engine and pressure vary. The equilibrium, or double-beat Cornish valves, can be set to any degree of cut-off or exhaust. When the steam is cut off as above, and D valves, or common slides, are used, an additional cut-off valve, or a great amount of "lap" is required, and a great pressure in the Boiler. "Lap" is added on the steam side of the valve, so that the

Diagram No. 33.

Taken from the Top of the Cylinder of a Condensing Engine.



steam port is only partially opened, and also so that it will close sooner in proportion to the amount of extra "lap." In such case the eccentric requires moving forward in proportion to the extra "lap" added. The pressure being great, and the steam port having sufficient room, allows the pressure to come upon the piston gradually, during the time the valve is partially open. The valve in that case does not open more than three-eighths of an inch, the steam being cut off when the piston has travelled

one-seventh the length of the cylinder. Where the pressure in the Boiler is 30lbs to the square inch, the opening on the steam side, if of one quarter of a square inch area for each nominal horse, will be quite sufficient, or that area of opening for each 22 square inches area of piston. The opening on the exhaust side should be at least one square inch area for each nominal horse. Where the valve box is too short, and where there is not room for "lap," the thoroughfares may be partially made up to answer the purposes of "lap."

Diagram No. 33, is from an Engine which has valves of the D construction. In this example, when the crank is at the "plumb-centre," the steam side of the valve is one-sixteenth of an inch open, and the exhaust-valve four-fifths open. The latter begins to close at eight-tenths the length of the stroke. The "lap," or cover, of the valve is also long at the end; and this "lap," or cover, has an additional breadth of face on the steam side greater than the width of the two "steam ports." This is for the purpose of cutting off the steam early. In all cases where "lap" is added, the eccentric should be moved forward, in the exact proportion of the "lap,"—providing there were little or no lead previously—which will give the same proportion of lead to the exhaust. Short slide valves, which are in general use for High-pressure Engines, derive advantages from similar arrangements. The principle of "lap," or cover, applies to both under similar circumstances. When the vacuum is bad, the closing of the exhaust requires to be later—because in consequence of there being steam left in the cylinder uncondensed, the exhaust requires to be kept open longer than would otherwise be necessary.

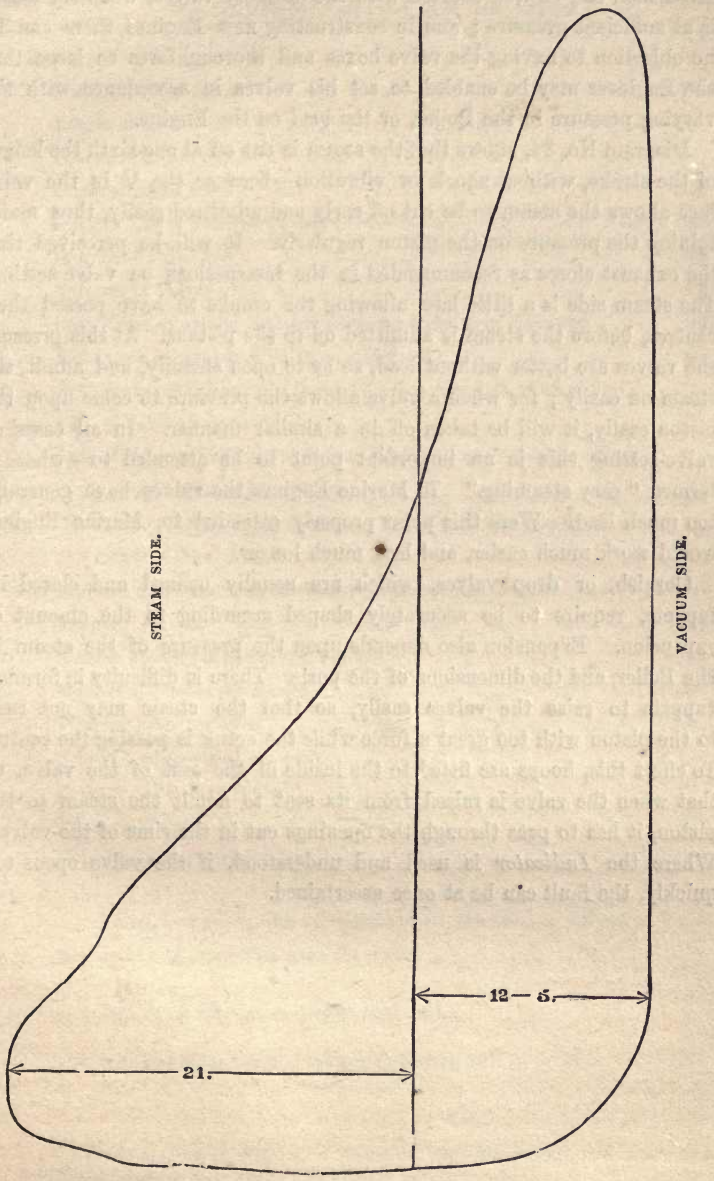
TWO ENGINES COUPLED, WORKING AT RIGHT ANGLES.

Diagram No. 34 is from one of two Engines coupled together, belonging to Messrs. SELLERS, of Burnley. The pressure of steam in the Boiler was 75lbs per square inch. The valves are of the common D construction, worked with the ordinary eccentric.

This case shows that valve-setting, with any description of valve, may be made to cut off at any part of the stroke, when the steam in the Boiler is of sufficient pressure. The valves and ports are not large, consequently they require an increased pressure of steam. When the steam is reduced to 45lbs per square inch, the Engines begin to lose speed, although there is not more than 21lbs per square inch upon the piston when the Engines are at full speed, because the "lap" on the steam side is so much that the port is not more than one-fourth open when the valve is at the extent of its traverse. The whole value of valve-setting and working expansively consists in having sufficient pressure in the Boiler; for in cases where the thoroughfares are small, the pressure

Diagram No. 34.

Taken from the Top of the Cylinder of a Condensing Engine.



makes up the difference. If the steam ports be large, expansion, or cutting off in the cylinder, is effected with less pressure in the Boiler—and that, too, without expansion valves or complicated apparatus. Expansion can be well effected with the ordinary valves, when the steam is at sufficient pressure; and in constructing new Engines there can be no objection to having the valve boxes and thoroughfares so large that the Engineer may be enabled to set his valves in accordance with the varying pressure in the Boiler, or the load on the Engine.

Diagram No. 34, shows that the steam is cut off at one-sixth the length of the stroke, without shock or vibration—because the V in the valve face allows the steam to be cut off early and admitted easily, thus maintaining the pressure on the piston regularly. It will be perceived that the exhaust closes as recommended in the instructions on valve-setting. The steam side is a little late, allowing the cranks to have passed their centres, before the steam is admitted on to the pistons. At this pressure the valves are better without lead, so as to open steadily, and admit the steam on easily; for when a valve allows the pressure to come upon the piston easily, it will be taken off in a similar manner. In all cases of valve-setting this is an important point to be attended to—what is termed "easy steaming." In Marine Engines the valves have generally too much lead. Were this point properly attended to, Marine Engines would work much easier, and last much longer.

Cornish, or drop valves, which are usually opened and closed by tappets, require to be accurately shaped according to the amount of expansion. Expansion also depends upon the pressure of the steam in the Boiler, and the dimensions of the ports. There is difficulty in forming tappets to raise the valves easily, so that the steam may not rush to the piston with too great a force while the crank is passing the centre. To effect this, hoops are fitted to the inside of the seat of the valve, so that when the valve is raised from its seat to admit the steam to the piston, it has to pass through the openings cut in the rims of the valves. Where the *Indicator* is used and understood, if the valve opens too quickly, the fault can be at once ascertained.

PROPORTIONS OF A PAIR OF 28* NOMINAL HORSE-POWER CONDENSING BEAM ENGINES, SHOWING THE MODE IN WHICH THE VALVES ARE SET.

(See Diagram No. 35, taken from these Engines.)

	Inches.
Diameter of Cylinders	28
Length of Stroke	60
Length of Steam Ports	14
Depth of Steam Ports	3¾
Cover or Lap of Valve steam side	3
Breadth of Valve face	5⅝
Traverse of Valves	7⅜
Both Exhausts open at each end when the Valve is in the centre	0⅜
Full extent of opening of Valve on steam side	0⅝
Full opening of Exhaust side (being 1¼ inches more than width of Port)	4
Lead of Valve on steam side	0
Lead of Exhaust at plumb-centre of Crank (being five-eighths of an inch more than width of Ports)	4⅜
Traverse of Piston when the steam is cut off; or near one-third the length of the Cylinder	19
Traverse of Piston when the Exhaust Valve begins to open	48
Vacuum	13½ lbs
Average pressure of Steam and Vacuum	12¾ „
Number of Strokes per minute	30
Working hours per week	60
Tons of Coal consumed per week	14
Pressure of Steam in Boiler	30 lbs
Injection Water	38°
Water from Hot Well	90°

Valves, long slides, with five-eighths of an inch bevel on the end of Valve, in place of a V exhausting down the centre.

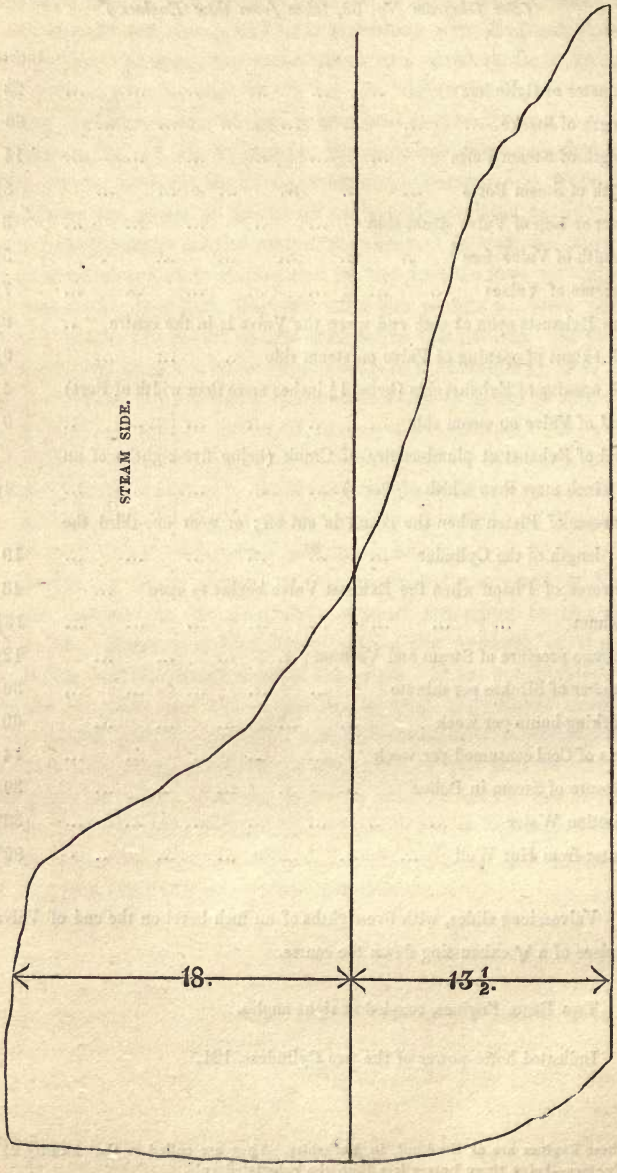
Two Beam Engines, coupled at right angles.

Indicated horse-power of the two Cylinders, 121.

* These Engines are at Bradford, in Yorkshire. They are called in that locality 25 horse-power Engines—being three horses less than the calculated rule.

Diagram No. 35.

Taken from a pair of 28 Nominal Horse Power Condensing Engines, at Bradford.—See Page 101.



A TABLE

SHOWING THE AMOUNT OF "LAP" REQUIRED FOR SLIDE VALVES, WHEN THE STEAM IS TO BE WORKED EXPANSIVELY.

The traverse of the valves being ascertained, and also the amount of cut-off desired, the following table shows the amount of "lap" required.

Traverse of the Valve in inches.	The traverse of the piston where the steam is cut off.								
	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{10}{12}$	$\frac{11}{12}$
	The required "lap."								
2	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$
$2\frac{1}{2}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
3	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$
$3\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{9}{16}$
4	$1\frac{3}{4}$	$1\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	1	$\frac{13}{16}$	$\frac{5}{8}$
$4\frac{1}{2}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{3}{4}$
5	$2\frac{1}{8}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	1	$\frac{13}{16}$
$5\frac{1}{2}$	$2\frac{5}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$
6	$2\frac{1}{2}$	$2\frac{7}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$	$1\frac{5}{16}$
$6\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{9}{16}$	$2\frac{7}{16}$	$2\frac{3}{32}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{4}$	1
7	3	$2\frac{11}{16}$	$2\frac{9}{16}$	$2\frac{3}{8}$	$2\frac{3}{32}$	2	$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{1}{8}$
$7\frac{1}{2}$	$3\frac{3}{16}$	3	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{3}{32}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$
8	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{3}{8}$	2	$1\frac{5}{8}$	$1\frac{1}{4}$
$8\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{5}{16}$	$3\frac{3}{16}$	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{5}{16}$
9	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{5}{16}$	3	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{3}{8}$
$9\frac{1}{2}$	4	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{3}{16}$	3	$2\frac{13}{16}$	$2\frac{3}{8}$	2	$1\frac{7}{16}$
10	$4\frac{1}{4}$	4	$3\frac{13}{16}$	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{1}{2}$	$2\frac{1}{16}$	$1\frac{1}{2}$
$10\frac{1}{2}$	$4\frac{7}{16}$	$4\frac{1}{4}$	4	$3\frac{1}{2}$	$3\frac{5}{16}$	$3\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{3}{16}$	$1\frac{9}{16}$
11	$4\frac{9}{16}$	$4\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{5}{8}$	$3\frac{1}{2}$	$3\frac{3}{16}$	$2\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{5}{8}$
$11\frac{1}{2}$	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{7}{16}$	$3\frac{7}{8}$	$3\frac{5}{8}$	$3\frac{3}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{3}{4}$
12	5	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{1}{8}$	4	$3\frac{5}{8}$	3	$2\frac{1}{2}$	$1\frac{7}{8}$

EXPLANATION OF DIAGRAMS.

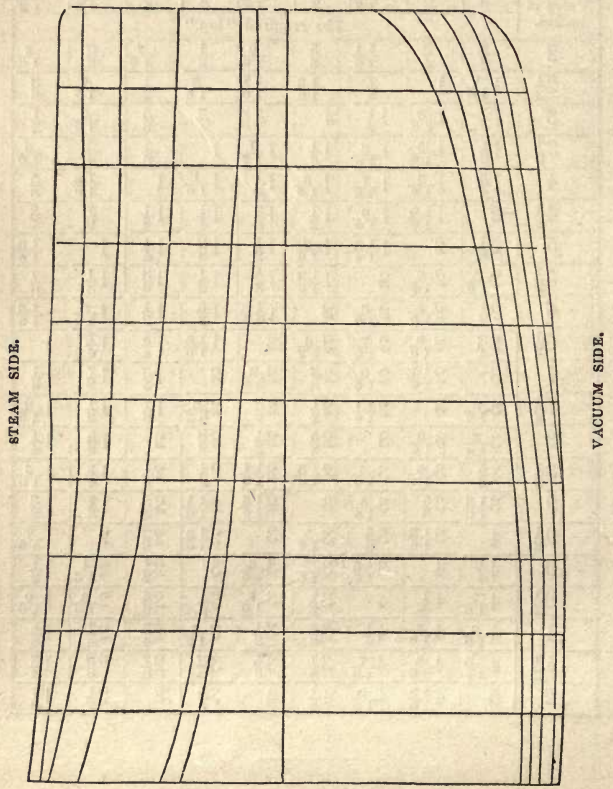
We now suppose the reader to have made himself practically conversant with the principles involved in the construction of the Steam Engine, and the construction of the common slide and other valves; also of the expansion of steam. If so, he will readily understand the explanations of diagrams which here follow, and be able to apply the instructions therein conveyed to his own case with advantage.

LIBRARY OF THE

No. 36 Diagram was taken from the Engine at Castle Mills, Sheffield, at the commencement of work after dinner. The *Indicator* was in operation until the whole of the work was propelled by the Engine, the diagram showing by the various lines, as the various machines were set to work, the extra quantity of steam required, and the decreased vacuum

Diagram No. 36.

Taken from the Top of the Cylinder of a Condensing Engine.



in proportion to the extra quantity of steam to be condensed. The different degrees on the diagram show, when measured, the power taken by each machine as it was put in motion. A similar result could be obtained where there are different rooms of machinery. Each room, as set to work, would describe on the paper the extra quantity of steam required to propel the machinery, and thus show the value or the cost of the power in each room. By this method we are enabled to ascertain the

power required for any particular machine, or number of machines, as well as the most economical amount of power the Engine will exert, in accordance with its construction, pressure of steam, size of condenser, dimensions of steam-ways, and the quantity and temperature of condensing water available.

The diagram shows the steam to be on the full length of the stroke. The valves were D valves, without "lap," consequently the steam was not cut off before the termination of the stroke. The pressure at the end is lessened, the difference in this case being caused by the condensation of the steam from the low temperature of the cylinder.

By Diagram No. 36 it is shown that the Engine has large steam-ways, as indicated by the great quantity of steam to be condensed at the termination of the stroke. If the eccentric was moved forwards, and "lap" added to the valve, less steam would be used, because the steam would be worked expansively, and the exhaust would be closed earlier, making a diagram rounded at the closing of the exhaust. The Engine would then work better, and the consumption of fuel would be considerably reduced. It will be observed that the various lines on the vacuum side are in accordance with the amount of steam to be condensed. The greater the quantity of steam, the less the amount of vacuum.

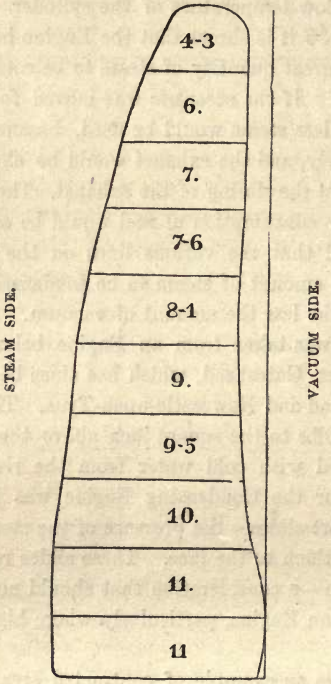
No. 37 Diagram was taken from an Engine belonging to Mr. John Davison, corn miller, Gateshead, which has since been destroyed by the great fire at Gateshead and Newcastle-upon-Tyne. The pressure of steam in the Boiler was 10lbs to the square inch above the atmosphere. This Engine was supplied with cold water from the river Tyne; therefore that useful agent for the Condensing Engine was in abundance. The valves were two short slides—the pressure of the steam upon the back of the valves pressing them to the face. These slides required considerable power to work them—a consideration that should not be lost sight of in the construction of an Engine, particularly where high-pressure steam is used.

This diagram gives an example of contracted steam-ways, and shows the crippled state of the Engine. The average pressure upon the piston is 7·2lbs to the square inch, with steam in the cylinder near atmospheric pressure at the commencement of the exhaust. Deduct the friction of the Engine and shafting at the regular allowance, 3lbs to the square inch, and the available power remaining is 4lbs to the square inch. Compare this diagram with Diagram No. 19. The average pressure upon the piston in No. 19 is 15lbs to the square inch, with steam in the cylinder at the commencement of the exhaust 6lbs below the pressure of the atmosphere. The one Engine has to condense fourteen, and the other nine, making a difference of 30 per cent. in favour of No. 19 Engine, in

the steam used and the steam to condense—showing the superiority of one Engine over the other. No. 19 Diagram shows 15lbs to the square inch, which, with 3lbs for the friction of the Engine and shafting taken off, leaves an available power of 12lbs to the square inch upon the piston —or three times the power of No. 37, with 30 per cent. less fuel used, and 30 per cent. less water for condensing.

Diagram No. 37.

Taken from the Bottom of the Cylinder.



Average vacuum, 7·2lbs.

The maker of the Gateshead Engine prided himself upon the superiority of this Engine over others, from the great noise the steam made on the exhaust side—he mistaking the noise for a good vacuum, when as shown by the diagram, the contrary was the fact. At this mill there were two Engineers at work, two Engines, two sets of Boilers, and more than four times the quantity of fuel used than was necessary. Had the Engine, No. 37, been properly constructed, it would have been able to propel more than both Engines were propelling, to say nothing of the daily expenditure being at least three-fourths reduced, and leaving out of question

the wear and tear, and the space uselessly occupied. Had either the maker or the proprietor been practically acquainted with the *Indicator*, it would have been of advantage to both. If the one had made a mistake, the other would have been able to point out the defect, and between them the Engine might have been put in proper working condition. Instead of this, however, they were both satisfied with it in its crippled condition; the one believing that he had constructed an Engine which could not be exceeded, and the other believing that his Engine was one of the best. As a proof that it was a good one, several people were called in to hear the good vacuum the Engine was making. The noise produced by the exhaust was similar to the noise made by the escaping steam at the top of a Locomotive Engine chimney. This is not a solitary instance of this kind of Engineering, but a sample of what may be frequently met with.

No. 38 Diagram was taken from an Engine belonging to Mr. RICKETTS, Corn Miller, Sheffield. By this diagram the state of the Engine will at once be apparent. The steam was too late, the exhaust was too late, and also closed too soon. In this state the Engine worked for a considerable time. There was a most irregular motion, causing the stones to tremble, and the whole machinery to appear in an agitated state. The Engine was consuming a great quantity of fuel, and by most parties it was considered overloaded. The valves were of the conical description, worked by revolving tappets. Several Engine-makers had examined the Engine, and various were their conjectures. At length, as a remedy, one of them applied several tons of metal to the rim of the fly-wheel. The result was not as anticipated: the additional weight—which had to be propelled!—did not improve the working, and the conclusion come to, after this alteration was, that the Engine was too small for the work it had to do. Diagram No. 38 was taken when the Engine was in this state.

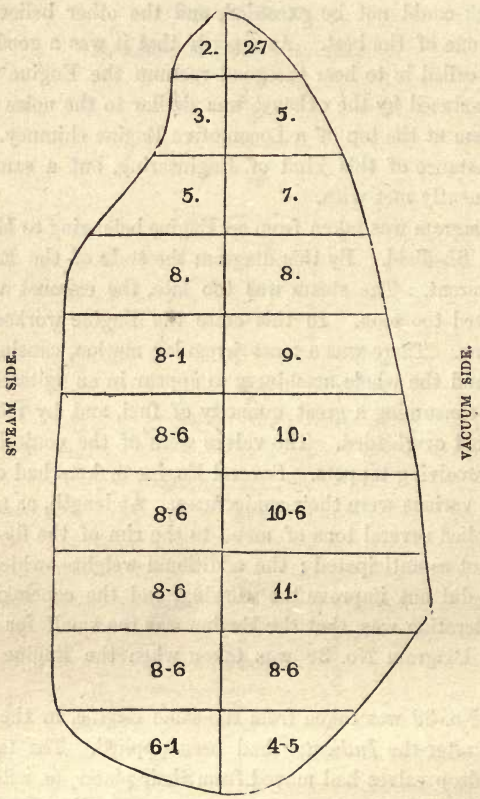
Diagram No. 39 was taken from the same Engine, in the short space of one hour after the *Indicator* had been applied. The tappets which worked the drop valves had moved from their places, as will be seen on reference to No. 38 Diagram. The tappets were adjusted, the *Indicator* again applied, and No. 39 Diagram obtained.

Examine the difference: the improved vacuum—the steam on at the proper time, cut off at one-fourth the length of the stroke—working by expansion—and the exhaust sooner. The average pressure of No. 39 Diagram is 10·86lbs, and the average pressure of No. 38 Diagram 14·30lbs; thus showing that the Engine, before the valves were properly set, was consuming steam equal to 3¾lbs to the square inch to work itself more than No. 39. The result of the alteration was, that the Engine

consumed little more than half the fuel it did before, the stones run steadily, the whole machinery at the proper speed, and sufficient surplus power remained to have driven one-third more work. This case shows pre-eminently the advantage and use of the *Indicator* over the guess-

Diagram No. 38.

Taken from the Top of a Condensing Engine Cylinder.



Steam 6·66lbs. 7·64lbs. Vacuum.
6·66 Steam,

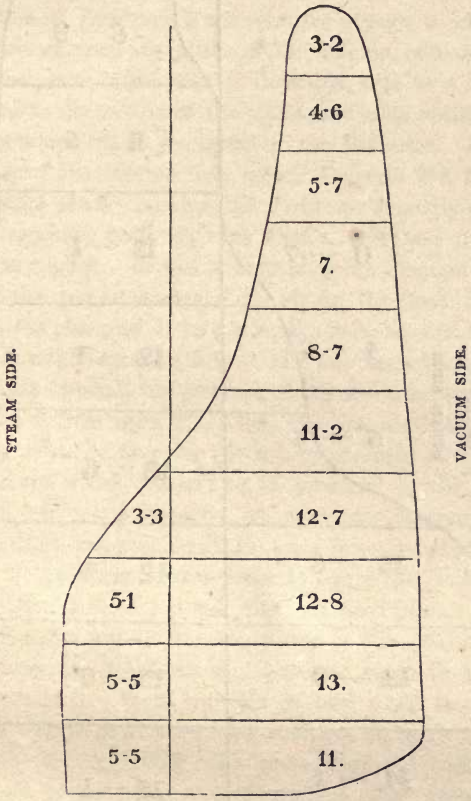
14·30 Average Pressure.

work of some Engine-makers and managers of Steam Engines. By its use the real defects were at once laid bare, and the simple remedy applied. An Engineer without an *Indicator* is like the Captain of a ship at sea without a *Compass.*

Diagram No. 40 was taken November 24th, 1855, from an Engine belonging to Messrs. HYDE, SONS, AND SOWERBY. This Diagram is also illustrative of our present subject, "Derangement of Valves"; and as there are numerous Engines working with valves set in a similar manner,

Diagram No. 39.

Taken from the Top of the same Engine as No. 38.



Steam, 1·94lbs.

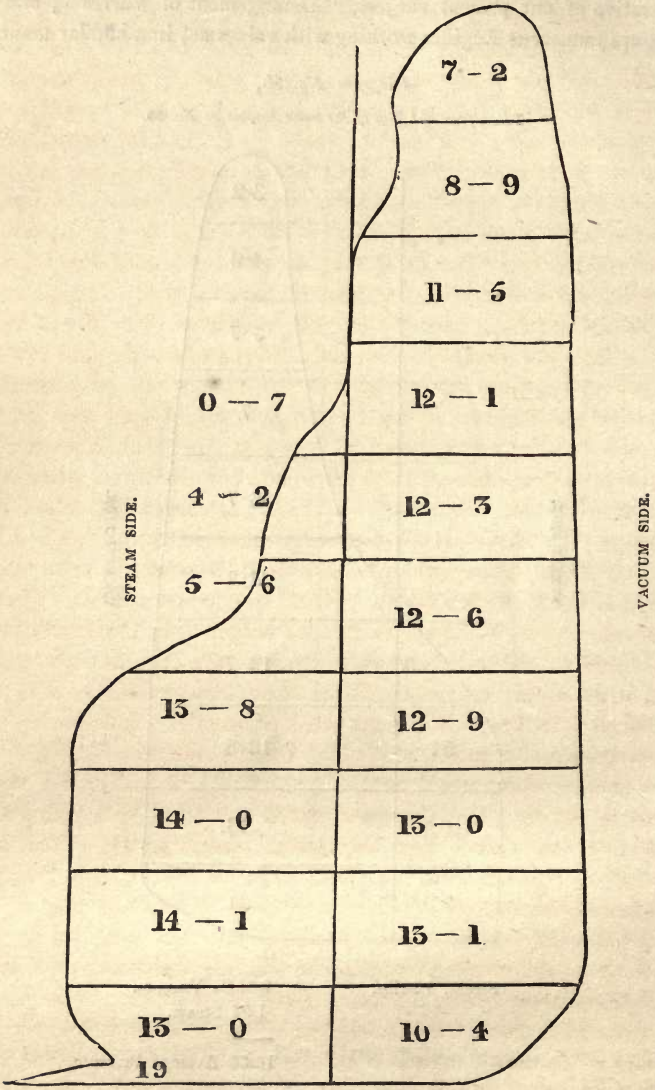
8·92lbs Vacuum.
1·94 Steam.

10·86 Average Pressure.

it is important that the facts and particulars of the case should be fully entered into and attentively considered; because a mistaken opinion exists amongst Engineers as to the cause of the irregularity which the diagram exhibits. Many suppose that the irregularity of the figure is

Diagram No. 40.

Taken from the Top of the Cylinder of a Condensing Engine.



Steam, 6·54lbs.

11·40lbs Vacuum.
6·54 Steam

17·94lbs Average Pressure of the steam on the piston throughout the stroke.

caused by the irregularity of action in the *Indicator*, arising from a want of correctness in the working parts, or from the spring of the instrument being too weak. In the present instance this idea prevailed ; and, as a proof that the irregularity arose from this cause, other diagrams were taken by a differently constructed *Indicator*, with the pencil projecting at a right angle from the cylinder—the barrel, or cylinder to which the paper is affixed being detached from the body of the instrument. This latter description of *Indicator* is not sensitive enough to show the true action of the steam upon the piston of the Engine, because the pencil-holder, with the pencil in the position described, acts as a lever with a motion opposed to the motion of the piston, and adds additional friction, preventing a true tracing on the barrel of the *Indicator*. It thus arose that the valves of the Engine from which Diagram No. 40 was taken were in the state shown, because the *Indicator* formerly used did not exhibit the irregularity made apparent when a larger and more sensitive instrument was applied. It will be seen from the diagram that on the steam side, at the commencement of the stroke, the steam is exerting a pressure upon the piston of 19lbs per square inch, the crank being then at the plumb centre. As soon as the crank has turned the centre, and the piston moved forward, the pressure of the steam is reduced to 13lbs per square inch. Then again it is raised to 14lbs, until the valve begins to close nearly at the half-stroke. It will be observed that here another irregularity occurs, which was said to be produced by the faultiness of the *Indicator*. In many instances where similar diagrams are taken, these irregularities are considered to arise from defectiveness in the instrument. Of course it is much easier to blame the *Indicator* than to explain its action. But to proceed with our description : the diagram shows that the steam was forcing the piston of the *Indicator* upwards against the spring, the resistance of which was equal to a pressure of 19lbs per square inch. Were not this so, how could the piston have been sent up ? There must have been sufficient force to overcome the resistance of the spring. This extra pressure at the beginning of the stroke—top and bottom—has a very injurious effect upon an Engine, and is the cause of more breakdowns and the breaking up of more foundations, than almost all other causes put together. Were the art of valve-setting more fully understood, so as to bring judiciously the pressure of the steam to bear upon the piston, we should seldom hear of Engines being stopped to repair breakdowns, which are now of constant occurrence, from the cause just explained.

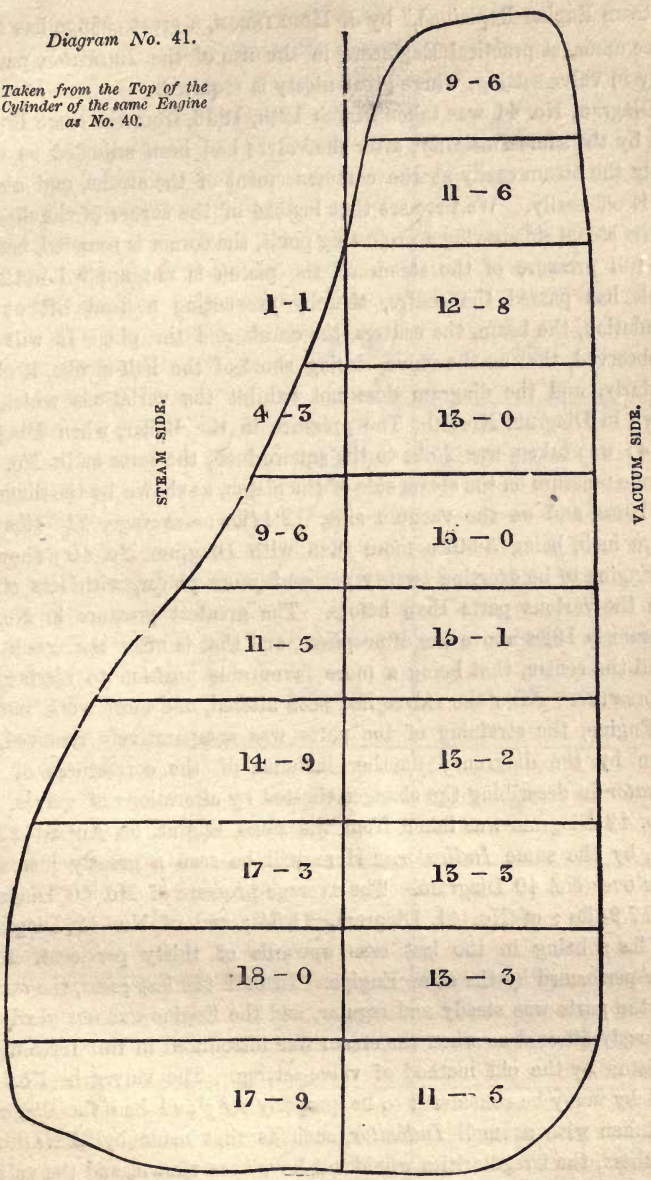
Wherever the *Indicator* makes a diagram similar to that of No. 40, it will be found that there is a great strain upon the pillars, beam, centres, crank, and other fixings of the Engine, which may be easily detected by placing the hands upon the parts, and particularly upon the pillars.

In Diagram No. 40, the pressure of the steam in the Boiler was 25lbs to the square inch. The diagram gives an average pressure throughout the stroke of 17·94lbs to the square inch. The average pressure of steam above atmospheric pressure is 6·54lbs, with a pressure upon the piston at the commencement of the stroke of 19lbs per square inch above the atmosphere. This extreme pressure being imparted to the crank at "plumb centre," every part of the Engine was thereby subjected to severe strain, there being on the beam, crank, and centres, a dead lift twice during every stroke. This was the result of the valve having too much lead, and of opening too quickly, so that the rush of the steam struck the piston of the Engine with great force in the same way as steam is applied to "the steam hammer." This caused the Engine to tremble, and be, to all appearances, heavily loaded. At the closing of the valve at half-stroke, the steam was reduced down too quickly. The diagram shews that the valve closed too rapidly, causing vibration and unsteadiness from the irregularity of the pressure upon the piston. This diagram exhibits the evil of steam being cut off too quickly, instead of being shut off regularly and easily: for it is as important for the steam to be taken off easily as for it to be let on easily, that the steady working of the Engine may not be disturbed. In the case we are considering, had there not being a heavy fly-wheel to overcome the sudden changes occasioned by the steam being thrown on and cut off too quickly, the vibration would have been much greater.

This mode of setting valves, with too much lead, of which Diagram No. 40 is a faint example, is a relic of the olden times, when low pressure steam was used from 4lbs to 10lbs per square inch. The practice is not nearly so objectionable with low pressure as with high pressure steam. Had there been a proper *Indicator* in use at the time we speak of, we should not now have had to combat the deep-rooted prejudices and mistaken opinions which prevail amongst those who have been in the habit of using the small *Indicator* with its pencil fixed contrary to the traverse of the *Indicator* piston. We shall have to shew in our further explanations of diagrams the evils which result from this description of instrument, and the injury done by parties who, without consideration, report on Steam Engines from diagrams taken by this defective instrument. In so doing, we shall give practical examples and facts to bear out our representations. We have only one object in view, that of dispelling the errors of those who ought to be more fully acquainted with the use and utility of a sensitive *Indicator* for valve-setting; and unless we give the names of the parties, and the circumstances we are commenting upon, others might be blamed. Since the publication of the practical facts contained in the early editions of the

Diagram No. 41.

Taken from the Top of the Cylinder of the same Engine as No. 40.



Steam, 9·10lbs.

12·44lbs Vacuum.
9·10 Steam.

21·54 Average Pressure of steam on the piston throughout the stroke.

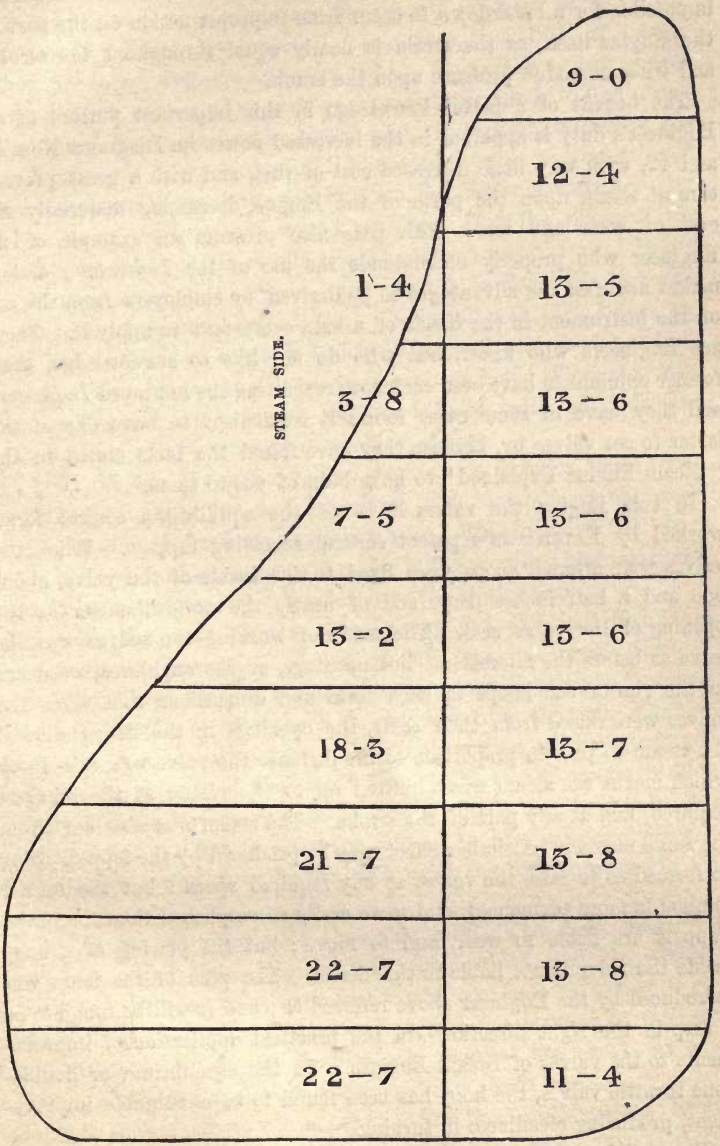
"Steam Engine Explained," by J. HOPKINSON, a great change has taken place amongst practical Engineers in the use of the *Indicator*, particularly in valve-setting, where great nicety is required.

Diagram No. 41 was taken March 12th, 1856, from the same Engine, and by the same *Indicator*, after the valves had been adjusted so as to apply the steam easily at the commencement of the stroke, and also to cut it off easily. We here see that instead of the corner of the diagram on the steam side having a projecting point, the corner is rounded, because the full pressure of the steam on the piston is not applied until the crank has passed the centre, thereby preventing a dead lift at the foundation, the beam, the centres, the crank, and the pin. It will also be observed, that on the valve closing short of the half-stroke, it closes regularly, and the diagram does not exhibit the variations which are shown in Diagram No. 40. The pressure in the Boiler, when Diagram No. 41 was taken, was 25lbs to the square inch, the same as in No. 40; average pressure on the steam side of the piston, as shown by the diagram, is 9·10lbs, and on the vacuum side, 12·44lbs :—average, 21·54lbs per square inch, being 3·60lbs more than with Diagram No. 40; showing the Engine to be exerting twenty per cent. more power, with less strain upon the various parts than before. The greatest pressure in No. 40 Diagram is 18lbs above the atmosphere, and that is after the crank has passed the centre, that being a more favourable position to receive the full pressure. After the valves had been altered, and more work put on the Engine, the straining of the parts was comparatively removed, as shown by the diagram; another instance of the correctness of the *Indicator* in describing the changes effected by alterations of valves.

No. 42 Diagram was taken from the same Engine, on August 23rd, 1856, by the same *Indicator*. Here will be seen a greatly increased power over No. 40 Diagram. The average pressure of No. 40 Diagram was 17·94lbs; of No. 41 Diagram, 21·54; and of No. 42 Diagram, 23·97lbs; being in the last case upwards of thirty per cent. more power performed by the same Engine. In both the last cases, the strain upon the parts was steady and regular, and the Engine was not nearly so injuriously affected as when the steam was introduced in full force upon the piston by the old method of valve-setting. The valves in No. 40 would by many be considered to be properly set; and had the diagram been taken with a small *Indicator*, such as that made by M'NAUGHT and others, the irregularities would not have been shown, and the valves would in that case have been passed as being correctly set. A state of things like these is too often the case, and forms one of the obstacles to the further improvement of the Steam Engine. When this defective instrument is relied upon, where one set of valves are found to be as well

Diagram No. 42.

Taken from the Top of the Cylinder.



Steam, 11·13lbs.

12·84lbs Vacuum.
11·13 Steam.

23·97 Average pressure.

set as in the instance we are illustrating, a greater number will be found to be worse. With valves set as in the case of No. 42, it would be almost impossible for a breakdown to occur from improper action on the part of the Engine itself, as the strain is nearly equal throughout the stroke, and without undue pressure upon the crank.

The benefit of a better knowledge in this important portion of an Engineer's duty is apparent in the increased power in Diagrams Nos. 41 and 42, with very little increased cost of fuel, and with a great prevention of strain upon the parts of the Engine, decreasing materially the cost of wear and tear. This case also presents an example of an Engineer who properly understands the use of the *Indicator;* and it makes manifest the advantages to be derived by employers from the use of the instrument in the hands of a man competent to apply it. There are Engineers who know, but who do not like to acknowledge, their former opinions to have been erroneous respecting the improved *Indicator;* and they have in some cases found it convenient to have one of the latter to set valves by, because they have found the facts stated in the "Steam Engine Explained" to have been of use to them.

In this Engine the valves were of the equilibrium conical form, worked by FAIRBAIRN'S patent vertical revolving tappets. When the valves were altered, hoops were fixed to the inside of the valve, about one and a half inches deep, and of nearly the same diameter as the opening of the valve seat. The mode of working the valves was the same as before the alteration ; but openings, or thoroughfares, were cut in the rim of the hoops of such form and dimensions, that when the valves were raised from their seats, the openings in the hoops allowed the steam to pass in proportion to the distance the valve was raised, by which means the steam was admitted on to the piston at the pressure required, and at any part of the stroke. The steam was also cut off in the same manner. A similar effect may be produced by the tappets being so formed as to raise the valves at any required speed : but the former method is more permanent, and more easily accomplished than the other. Tappets are liable to wear, and to move ; but the placing of a hoop inside the valve is not liable to this defect. The plan of the hoop was introduced by the Engineer above referred to ; and it will be found to be a step in the right direction—in the practical application of improvements to the valves of Steam Engines. To the equilibrium or double-cone throttle valves, the hoop has been found to be a valuable improvement, producing steadiness in turning.

By studying the last three diagrams, those conversant with the improvements therein shown, as having been made in the working of the Engines, and of the increase of real power obtained from the same

nominal force, will at once see the advantage of good management over the bombast and guess-work of those who are ignorant of the use of the *Indicator*, and who rely upon the reports made to them by the Inspectors of "Boiler Associations," "Insurance Societies," &c., many of which are found oftener wrong than right. Unless the modern system of centralisation and company-making, intended principally to find places for theoretical Engineers, be discountenanced, the further progress of the Steam Engine will be much retarded. In the three instances, just referred to, the recommendations in the reports from the Boiler Association were found to be at variance with sound practice. Had the advice of the Inspector been followed, the results would have been very different. In one case, the suggestions in the report were adopted, to show the Inspector his own want of practical knowledge. The result was, that before the Engine had worked two hours, it had to be stopped, and the alterations reversed. This led to the Inspector's services being dispensed with. Where an Engineer is driving his Engines without using an *Indicator*, proper working will be merely the result of chance.

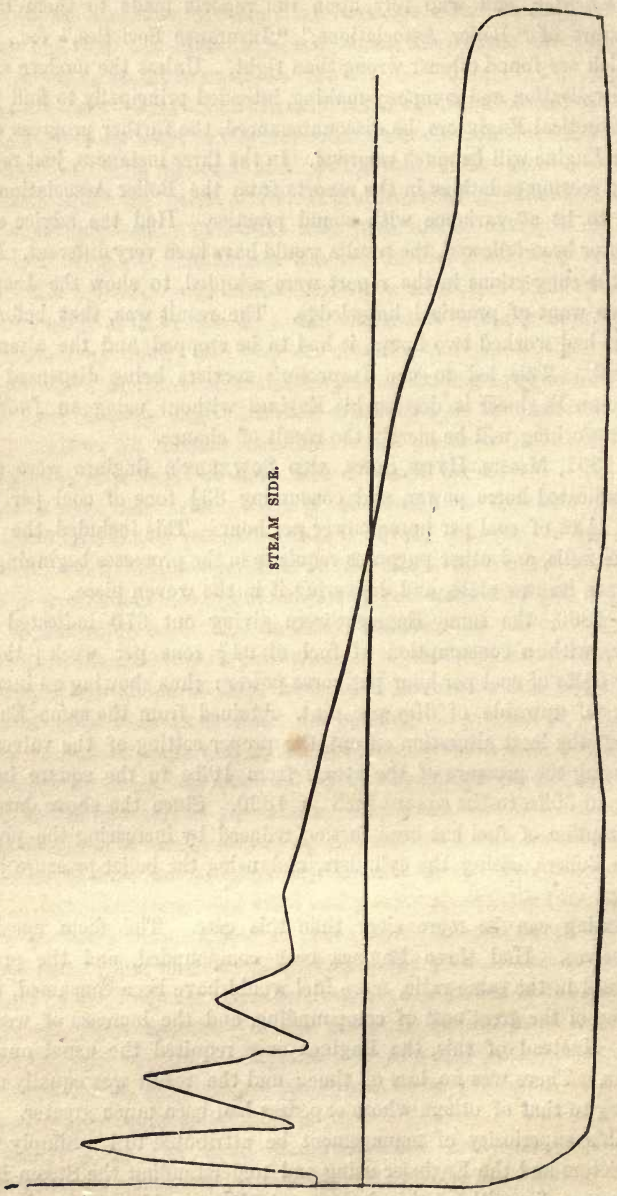
In 1851, Messrs. HYDE, SONS, AND SOWERBY'S Engines were giving 415 indicated horse power, and consuming $83\frac{1}{4}$ tons of coal per week, being $7\frac{1}{2}$lbs of coal per horse power per hour. This included the steam for the mills, and other purposes requisite in the processes beginning with cotton in its raw state, and delivering it in the woven piece.

In 1860, the same Engines were giving out 670 indicated horse power, with a consumption of fuel of $94\frac{3}{4}$ tons per week; that is, under $5\frac{1}{4}$lbs of coal per hour per horse power: thus showing an increased power of upwards of fifty per cent. obtained from the same Engines, without the least alteration except the proper setting of the valves, and increasing the pressure of the steam from 10lbs to the square inch in 1851, to 30lbs to the square inch in 1860. Since the above date, this consumption of fuel has been further reduced by increasing the pressure in the Boilers, casing the cylinders, and using the boiler-pressure in the casings.

Nothing can be more clear than this case. The facts speak for themselves. Had these Engines been compounded, and the pressure increased in the same ratio, more fuel would have been consumed, to say nothing of the great cost of compounding, and the increase of wear and tear. Instead of this, the Engines only required the usual outlay in repairs. There was no loss of time; and the result was equally steady turning to that of others whose expenses had been much greater. What can this superiority of management be attributed to? Simply to the proprietors and the Engineer using and understanding the Steam Engine *Indicator;* for without this instrument they would not have been able

Diagram No. 43.

Taken from the Top of the Cylinder of a Condensing Engine.



to increase and regulate their power, but would have been like many — continually guessing as to what the result of various alterations would be.

Diagram No. 43 was taken from an Engine belonging to Mr. SAMUEL COOKE, of Mill Bridge. This is another example of improper valve-setting, and of the most frequent cause of Engines breaking down. The pressure of the steam in the Boiler, when this diagram was taken, was 30lbs to the square inch. The diameter of the cylinder is 42 inches: the thoroughfares each 20 inches long, and 5 inches wide. The valves are two short slides. When the crank was at the "plumb centre," the steam side of the valve was one-eighth of an inch open the full width, and the exhaust side two and a half inches open. The pressure of the steam upon the piston, when the crank was at the "plumb centre" was 20lbs per square inch above atmosphere. When the crank had passed the centre, the steam was reduced down to 5lbs per square inch, which was all the Engine required for the work it had to do; and this amount of pressure ought not to have been exceeded at any time for the amount of power given out, unless the valves had been set to work the steam expansively. As before observed, 20lbs was brought upon the piston; but this 20lbs did not act as steam giving out power to work the machinery, but only as a force to break up the Engine. The great strain thus cast upon the Engine would in time have caused the foundation to give way; and there was every probability that either the beam, the beam centres, or the crank would break. Such occurrences are not unfrequent. When they happen they are often ascribed to anything but the proper cause; and to prevent the recurrence of such disasters, stronger parts to the Engine are substituted, as the others are deemed too weak— when, in fact, they were fully strong enough had the valves opened and closed at the proper time, and at a proper speed.

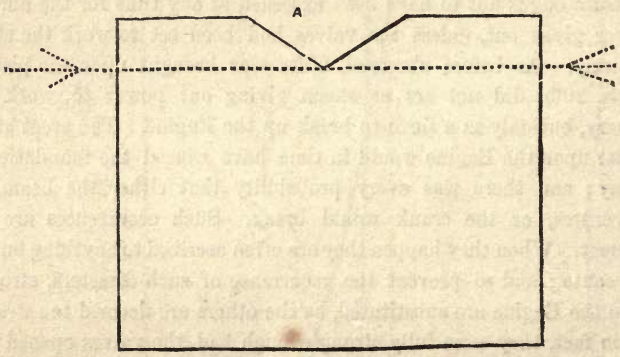
In the case now under consideration, the valves were set and left working without the *Indicator* having been applied, although the proprietor had one in his possession. The result was, the valves were in the state described. If the proprietor had not known the use and advantage of the *Indicator* better than the Engineers who erected his Engine, in all probability it would have continued in the state as left by them, until it had tumbled to pieces. To remedy the defect, the valves required more lap, and less lead on the steam side. With the size of steam-port provided in this case, the opening would be too large at the beginning. In such a case the required opening can be obtained and regulated by cutting the valve edge in the form of the letter V, as shewn in the following engraving.

The V portion is taken out at A, that the steam may be admitted upon the piston gradually; the dotted line shewing the amount of lead (or no

lead) on the steam side when the crank is at the plumb centre, before the valve opens to full pressure.

It will at once be seen that as the valve moves forward, the opening increases in size. The crank will have passed the centre before the valve has opened to the whole length of the thoroughfare, or so much as is required; the strain will thereby be taken off the Engine, and the piston and crank will be prepared to receive the full pressure of the steam. By these means the force exerted is properly applied, instead of being expended in a dead lift upon the beam, the centres, and other parts of the Engine itself. By adding more lap to the valve, the steam would be sooner cut off, and more pressure thereby brought upon the piston during the time the valve was open: thus working more expansively, and consequently more economically. This ought to have been the case

No. 44.



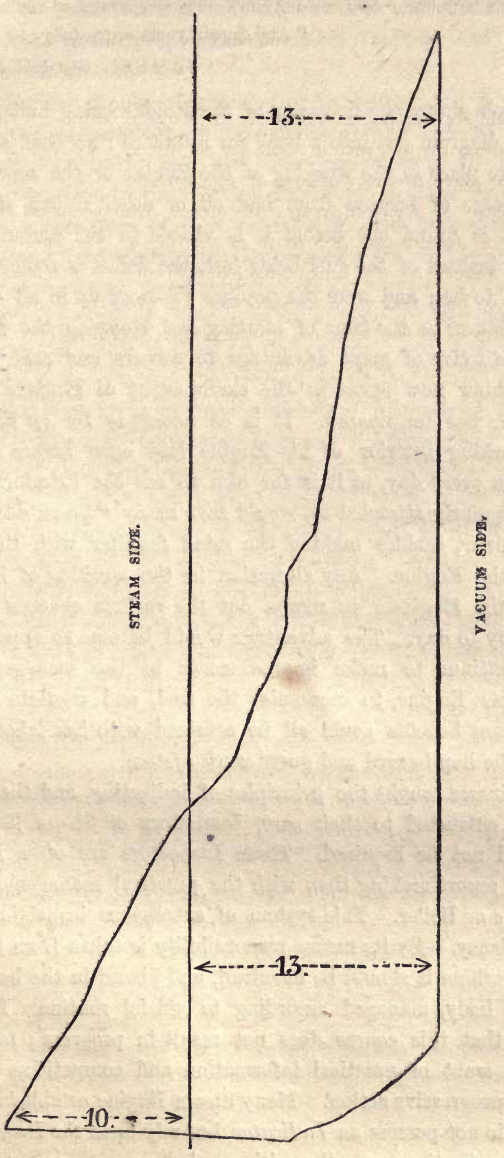
A, the V shaped grove made in the Valve edge.

in the instance under consideration, as there was 30lbs pressure in the Boiler. We often find that the pressure in the Boiler is no criterion or measure of the pressure in the cylinder, or the power the Engine is exerting; and it often happens that where there are no means of indicating the Engine, great discrepancies arise, and alterations are made without data, or knowledge of the real state of the Engine. These generally result in loss of fuel, in repairs, and in loss of time.

Diagram No. 45 is from the same Engine as No. 43. It will be perceived that the steam expands to the lowest practical quantity, making the most of it, and taking little water to condense with. It will be apparent that the steam is not so soon on the piston, and that the exhaust opens earlier. A very slight alteration made the difference as before explained. The following letter was received with the diagram:—

Diagram No. 45.

Taken from the Top of the same Engine Cylinder as No. 43.



"*Liversedge, near Leeds, May 29th*, 1861.

"Messrs. HOPKINSON & Co.

"GENTLEMEN,—We have made the alteration (suggested by your Mr. HOPKINSON, when last here) on the exhaust side of the valves. Except the wavy line on the steam side, we think we have now a very fair diagram. Enclosed we beg to hand a copy,

"And remain yours respectfully,

"SAMUEL COOKE & SON."

This example shows the necessity of the Engine being indicated every day, and the diagram put into a book for reference : so that should any alteration take place in the working of the Engine or the machinery, or even an increase of friction from bad oil or other causes, it is easily detected. It is found out before it is visible in the amount of fuel wasted ; and instead of the fuel being lost, the defect is remedied. This is as it ought to be ; and were the practice followed up in all cases with the same exactness as the time of starting and stopping the Engines, it would be productive of great advantage to owners, and save Engineers many a late hour now spent in the examination of Engines after the work of others has terminated. It is as necessary for an Engineer to have the working interior of his Engine laid open before him in a diagram taken every day, as it is for him to see the exterior. Such a practice, if regularly attended to, would save many "break-downs" and expensive repairs, besides making the mind familiar with the internal working of the Engine. Any alteration in the working of his Engine would cause the Engineer to reason out the various changes that take place from day to day. The advantage would become so apparent, that he would continue to make improvements in the management and working of his Engine, to economise the fuel, and regulate the speed. These important benefits could all be attained with less labour than is entailed by the hap-hazard and guess-work system.

Were Engineers taught the principles of indicating, and the nature of the machine entrusted to their care, Inspectors of Steam Engines and Boilers would not be required. These Inspectors are often more conversant with report-making than with the practical management of the Steam Engine or Boiler. This system of extraneous inspection is retrograde in tendency. By its means responsibility is taken from the proper parties upon whom it should be devolved, and placed in the hands of an irresponsible body, managed according to official routine. Experience has proved that this course does not result in progress ; for under it there is the want of practical information and competitive power to stimulate to progressive action. Many Steam Engine establishments and Mill owners do not possess an *Indicator*, but rely upon the Inspector, who may call once in three months with an instrument—one adopted by

official power, small in construction, and not very sensitive. To carry a larger one would be too burdensome to the Inspector, although it is better calculated to give a diagram that could be properly read. Under such circumstances, the Engineer is left to grope his way,—a state of things that may be sustentative of officials, but it is not advantageous to the manufacturers or the proprietors of Steam Engines, and it certainly is detrimental to science.

If the amount of money expended in Lancashire and Yorkshire in the formation and sustentation of "Associations" to remove responsibility from where it ought to rest, had been expended in the scientific and practical instruction of the working Engineers of those two counties, the result would have been of a more valuable and permanent character: for the latent talent which often lies concealed in humble positions would then have a chance of devolopment. Such a course, at any rate, would have taught the working Engineers, as a body, to understand scientific principles as applicable to their art and calling; and also enabled them to understand in practice the motive power entrusted to their care. They would thereby have been enabled to understand the force and bearing of "Reports" emanating from any "Association," and practical science would thus have received a stimulus. Instead of this, however, the working Engineer has been considered to be only a machine to perform the functions prescribed by others, while the "Report"-maker has been elevated into the position of "official" dictator.

The following letter from a working Engineer, on the principle of expanding steam in one cylinder of a Non-condensing Engine, is another proof of practical experience over "office" Engineering and official routine :—

"*Duckinfield, April 5th*, 1857.

"Mr. J. HOPKINSON.

"SIR,—I wish to draw your attention to the particulars of an experiment with a High-pressure Engine, which I have been conducting at the Central Works, Sheffield, belonging to Mr. SHORTCLIFFE. The Engine had a nine-inch cylinder. The steam was admitted during the whole length of the stroke, without expanding. The Boiler evaporated 900 gallons of water in five hours, with a weekly consumption of twelve tons of coal. The pressure was 72lbs per square inch in the Boiler, and yet they could not maintain the speed of the Engine when all the work was on.

"The alteration which was made was simply replacing the nine-inch cylinder with one of thirteen inches diameter,* and arranging the valves so as to cut off the steam before the piston had travelled half the length of the cylinder, allowing the steam to expand the remainder of the stroke.

"Sir, if I must state what was the general impression amongst the Engineers of Sheffield, it was to this effect: that the new cylinder would drive the work, provided there was an additional Boiler to supply it with steam. Only imagine their surprise,

* The area of the nine-inch cylinder is 63½ inches, and of the thirteen-inch cylinder, 132¾ inches square—nearly double the size.

when they found that the Engine was driving the whole of the work at the proper speed, and the Boiler only evaporating 415 gallons of water in five hours, at 55lbs pressure—less by one-half than what was required before; and this, too, with half the firing. Instead of requiring another Boiler, we had half the present Boiler to spare for other purposes.

"Since the alteration, additional work has been added to the Engine; still the weekly consumption of coal is only seven tons.

"This result, good as it is, is nothing more than you would expect from allowing the steam to expand, over that of no expansion at all.

"In travelling the country, I find that a great number of owners of Engines have yet to derive the advantages which others are deriving, by allowing the steam to expand before leaving the cylinder. The reason of this is, that the means of carrying out expansion and early exhaust are but little understood by those who ought to have a practical knowledge on the subject. No doubt one great cause is a want of a more general knowledge of the *Indicator*, and its frequent application, in order to obtain that information which it is enabled to convey respecting the interior of the Engine.

"The diagrams from the Condensing Engine I enclose will show you the former and present state of the Engine alluded to. By the first figure it is apparent that the valves were in such a state that 63 indicated horse power was the very utmost the Engine could drive at the proper speed. It is now working 146 horse power, with a less consumption of steam than before.

"I feel convinced that parties who wish to work their Engines with economy, can accomplish that purpose by applying the *Indicator*, and studying the cause of its peculiar delineations upon the paper. By this means they may obtain a sound knowledge of the working of any Engine, and ascertain where improvement is practicable.

"I confess I am greatly indebted to that instrument, and remain,

"Yours truly,

"ENOCH GLEDHILL."

In the case referred to, great advantages have been derived from the alteration detailed. Similar results would have been obtained by using the small cylinder, with an increased pressure of steam, worked expansively.

It is from the high-pressure expansive principle alone that we are enabled to travel at great speed on railways; and it cannot be controverted that High-pressure Stationary Engines are, on the average—for the effects produced—consuming more than double the quantity of fuel to that consumed by Locomotives. So little do makers of High-pressure Engines appear to understand the principle of using steam expansively, that it is rare to meet with a High-pressure Engine with its valves set to cut off the steam until very near the termination of the stroke. The exhaust has almost invariably too little "lead," and the thoroughfares are too small; thereby entailing a back-pressure upon the piston—or, in other words, a loss of power. The hints here given will indicate to the practical Engineer how the remedy is to be applied; and if this be effected judiciously, similar beneficial results to those detailed above will follow.

DIRECT-ACTING HORIZONTAL CONDENSING STEAM ENGINES.

The Frontispiece of this book represents a 20 nominal horse power Direct-acting Horizontal Condensing Steam Engine. It contrasts greatly with the beam construction hitherto generally applied to Condensing Engines. The great change now taking place with regard to the form, construction, and working of Steam Engines, is a subject on which we might dwell at great length; but we here content ourselves by giving this plate as an example of one of the departures from the ordinary construction. The economy in construction and room, besides the advantage of strength combined with simplicity—there being fewer parts for wear and tear—should be inducements for its adoption. Should a breakdown occur, the damage will be much less, compared to such an occurrence with a Beam Engine, with its massive beam, connecting rod, pillars, &c.

On reference to the plate, it will be seen that the condenser and air-pump are placed at the back end of the cylinder, in a place easy of access. The air-pump is worked by links from the back piston-rod attached to a bell-crank; the cylinder valves are worked by the ordinary eccentric; and the Engine is governed in the usual way. The whole of the working parts are bound together on one frame, and are, therefore, not liable to be separated or strained by the foundation or building giving way.

By some parties it has been urged that the lower portion of the cylinder of a Horizontal Engine wears more than the other parts. This objection is not verified in practical working. With the cylinder placed horizontally, it is found to work equally as well as a vertical cylinder and piston—and in the same way, too, wearing the cylinder a little wider in the centre. Of course the horizontal cylinder requires, like all other cylinders, to be made of a good quality of metal; and then, when worked with a metallic piston, there is little chance of any uneven wear.

All the parts of the Engine should be well balanced, to produce equal motion, and the air-pump should have as short a stroke as convenient. In a 40-horse Horizontal Condensing Engine at the works of the Messrs. HOPKINSON, the stroke of the piston is 4ft. 6in.; the stroke of the air-pump, single action, is 12in. The speed of the piston is 400 feet per minute. There cannot be a doubt that Direct-acting Engines are the best. Where there are numerous parts and great weights to be kept in motion, more power is required than where the parts are fewer and simpler.

CHAPTER III.

THE STEAM ENGINE INDICATOR.

HISTORY OF THE INSTRUMENT.

THE Instrument known by the name of the *Steam Engine Indicator* was invented by the celebrated JAMES WATT—a man whose name is indelibly associated with the improvement of the Steam Engine. The genius of WATT, combined with the facility of practical application possessed by him in an eminent degree, enabled him to become one of the greatest promoters of civilization, by placing at the command of his species a motive power for manufacturing and industrial operations almost illimitable. Having by his improvements created, as it were, this new motive power—the Steam Engine—an instrument to enable him to measure the definite amount of the power of each Engine, and to indicate defects in construction or working, became to him an indispensable requirement. To supply that want, he devised what is at present known as the *Steam Engine Indicator*. For a considerable period WATT kept the knowledge of that useful instrument to himself; but having at length to send a Steam Engine abroad, and the responsibility of its erection and proper working devolving upon the firm of which WATT was a member, he furnished a mechanic, whom he sent out to superintend the erection of that Engine, with an *Indicator*, having previously instructed him in the art of its application: showing him that by its aid he could set the valves of the Engine so as to produce the greatest effect from a given quantity of impulsive power. It was to this circumstance that the Engineering profession are indebted for this most valuable instrument; for, as will readily be imagined, a knowledge of the important aid it was calculated to render to the practical mechanic having been thus imparted, it could not long be kept secret, as WATT had hitherto kept it.

Since the period we speak of, the *Steam Engine Indicator* has received several minor, but important, improvements. In principle, it is as it left the hands of WATT; it is only in detail where alterations and improvements have been made. Mr. SOUTHERN, an ingenious mechanic in Messrs. BOULTON & WATT'S service, added the revolving cylinder, with its attached paper and pencil, in place of the former traversing board, to enable the instrument to register its own observations. Some

makers have this revolving cylinder detached, or apart, from the other portions of the instrument ; but Messrs. HOPKINSON find by experience —the test of all improvement—that it is best to have the revolving cylinder placed upon the steam cylinder of the *Indicator*, because it is in that place the most convenient and firm for the operation which has to be performed upon it. The pencil holder should be parallel to the cylinder piston, as by that mode the instrument is rendered the most sensitive, and, as a necessary consequence, the most correct indications are obtained. This improvement, though a minor one in appearance, will hereafter be shown to be of considerable importance. The difference of the indications given by this instrument will be shown by contrasting its diagrams with those given by the description of instrument called the M'Naught and the Richards, on which the pencil operates at right angles to the traverse of the piston, and where the revolving cylinder is detached from the body of the instrument, and as in Richards' *Indicator*, where the pencil is fixed to levers, to increase the size of the diagram. It will at once be seen that a tremulous or unsteady motion of the pencil on the revolving cylinder must impart a corresponding effect to the diagram, and is therefore calculated to lead to erroneous conclusions in the modes of valve-setting—points of extreme nicety as to the actual condition of the Engine, or the minute alterations of its working parts which may be required to secure the greatest effect with the least expenditure of power.

In several other particulars Messrs. HOPKINSON have improved the *Steam Engine Indicator* for practical use. The instruments of their manufacture are not flimsy in construction : and care is taken to have all the working parts truly and accurately fitted, so as to produce true and steady motion, with the least possible friction. Messrs. HOPKINSON have no hesitation in asserting that in these particulars the instruments of their manufacture will commend themselves, and that the practitioner will find the new arrangement both convenient and useful. The diagrams taken by the *Indicator* manufactured by the Messrs. HOPKINSON are much larger than those usually taken by the instrument as commonly constructed, while the vacuum side of the diagrams is never decreased, whatever the pressure of the steam. The inch is divided into tenths on the vacuum side, one-tenth representing 1lb pressure per square inch. This scale also applies to the steam side, for low pressures up to 25lbs. For high pressures up to 75lbs, the inch is divided into thirtieths, one-thirtieth part of an inch representing 1lb pressure. From this arrangement the diagrams are much more readily divided and "read off," and the defects in the working of the Engine more clearly shown, than by the ordinary mode. Experience has shown that the working cylinder of the *Indicator* should be drawn out of brass tubing. By this method it is

much truer and harder, and if the piston be well ground in, the working of the instrument will be more accurate, and assist the operator in setting his valves with greater precision : advantages which cannot fail to be appreciated by those for whose use and benefit the instrument has been designed and improved.

At the Exhibition of 1862, an American *Indicator* was shown, and it was stated in its prospectus, and also by a portion of the press, that it possessed advantages over others in taking diagrams from Engines working at quick speeds. No doubt the editors of these journals thought so, but had they been practically acquainted with the subject, they would have known that the reverse was the fact—that the difficulty of indicating quick-speeded Engines with such an *Indicator* was the revolving of the barrel backward and forward with a coiled spring, the American *Indicator* being similarly constructed in that respect to the English ones, and in other parts even much more complicated.

ADVANTAGES OF THE STEAM ENGINE INDICATOR.

With the *Steam Engine Indicator* a person may, at any time when his Engine is in motion, ascertain the working condition of that Engine —find out its defects—measure the power it is exerting—ascertain the difference of the pressure of steam upon the piston and within the Boiler —and, at every part of the upward or downward stroke, know the exact pressure of the steam upon the piston at its various distances from the bottom to the top, and from the top to the bottom : also ascertain the amount of *lead* the valve is working with, on the steam and exhaust sides. The *Indicator* thus enables the operator to calculate with accuracy the pressure of steam exerted on the average throughout the whole length of the stroke—and learn at what part of the cylinder the piston is when the valve opens or closes, and what quantity (if any) of expansion he is working with. At one glance of the diagram he will have the interior—the inner working—of his machine, laid open as it were to view ; its good qualities and its defects registered on paper by the Engine itself : thus dispensing with that system of guess-work often resorted to by Engineers who pretend to know defects and derangements by the working and beating of the Engine : a kind of fortune telling which many proprietors of Steam Engines have had to pay dearly for. Without the *Indicator* and some experience in its use, and without a proper knowledge of the diagram when taken, no man ought to be allowed to alter or set up a Steam Engine to work, or to take the management of its working ; for it is otherwise impossible to know anything of the inner working of

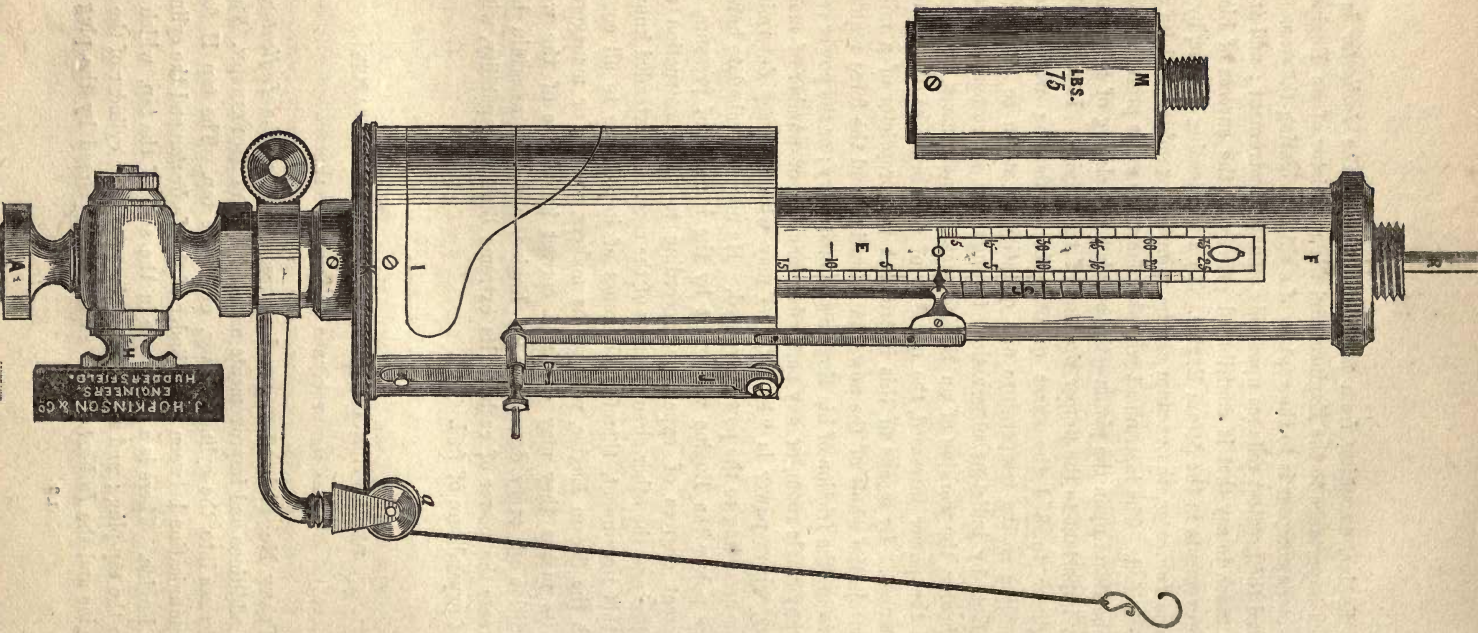
the Engine, excepting from mere conjecture. The *Indicator* is of as much importance to the Engineer and the proprietor of an Engine as a mariner's compass is to the captain of a ship navigating the seas. WATT placed the greatest reliance upon this valuable instrument; and it is not too much to say that it contributed greatly to the success of his many improvements in the Steam Engine. In a Condensing Engine, by means of the *Indicator*, the vacuum can be minutely examined and its quality ascertained. The instrument will also show the exact pressure and time of the steam upon the piston—the opening and closing of the exhaust—very important to the proper working of the Engine. It will enable the Engineer to find the exact quantity of condensing water required, according to the temperature and quantity of steam to be condensed. In fact, by judicious observation, through the instrumentality of the *Indicator*, the working of an Engine may, in most cases, be improved, and the power increased, the quantity of fuel being at the same time decreased. By means of this instrument the proprietor of a mill may ascertain the whole of the power in operation, and the force required to overcome the friction of his Engine and machinery; or the power required for any single room, or any particular machine or number of machines. Thus, where power is "let off," he may with accuracy determine the value according to the power required. He may also calculate how much more power the Engine will exert by the increase of pressure, or the different degrees of expansion, according to the construction of his Engine and the other circumstances of the case. An extended knowledge of this instrument, therefore, becomes of importance to all connected with the Steam Engine, whether as makers, owners, or managers: for by its means they may obtain a correct knowledge of the working condition of every description of Engine, and also ascertain how to increase the power of each to its extreme limit of capability, with the least expenditure of fuel.

DESCRIPTION OF THE STEAM ENGINE INDICATOR,

AS MANUFACTURED BY MESSRS. HOPKINSON.

PLATE No. 46 is an engraved representation of the *Indicator*, with the additions and improvements made by Messrs. HOPKINSON. The plug A screws into the cylinder cover, or grease tap. The tap H forms a communication between the cylinder of the *Indicator* and the cylinder of the Engine. There is a small hole in the side of the tap, which opens into the tap-plug; and when the tap is open to the cylinder of the Steam Engine and the *Indicator*, this small hole is closed by the plug being

PLATE No. 46.



turned with its perfect side against the hole. When the tap is closed, the connection with the Engine cylinder is cut off. The small hole in the tap is then open through the plug to the cylinder of the *Indicator*, so that any steam remaining between the piston of the *Indicator* and the plug of the tap may escape into the atmosphere, and allow the pencil attached to the piston of the *Indicator* to settle down to the atmospheric line. The cylinder of the *Indicator* is fitted with a piston, the rod of which is shown at R. This piston is accurately ground into the cylinder, thereby avoiding packing; and, when properly oiled and cleaned, it is steam-tight, except at very high pressures, where perfect tightness is not required, as any small portion of steam which may escape cannot affect the bulk of the pressure in the cylinder. From this construction, the piston works freely, with little friction. The piston-rod R is attached to the spiral spring S, within the tube or casing F, placed above the steam cylinder of the instrument. This spring is so adjusted, that when the piston index is forced one-tenth of an inch above the atmospheric line 0, marked on the scale E, it represents 1lb pressure of steam. The pointer forced *upward* each tenth of an inch, up to 25 tenths, will represent as many pounds pressure to the square inch. In the same way, when the vacuum is formed in the Engine cylinder, the spring will be distended by the pressure of the atmosphere upon the upper side of the *Indicator* piston, and the piston will be forced *downward* as many tenths of an inch as the degree of rarity, or the quantity of steam extracted from the Engine cylinder in pounds per square inch below the pressure of the common atmosphere. Affixed to the casing there is the scale E, with the atmospheric line 0 in the centre. The tenths below 0 to 15, indicate the vacuum; and above 0 to 25 tenths, the steam pressure above the atmospheric pressure. The pencil-holder G is attached to the piston-rod R, through an aperture cut in the casing F, to allow the pencil-holder to move up and down with the piston-rod of the *Indicator*. The pencil can be screwed backward or forward to obtain the exact length required, and is adjusted by a spring to allow it to accommodate itself to any little inequalities there may be on the revolving cylinder or the paper. In all cases a soft and good pencil should be used. The less the pressure upon the paper, the less the resistance to the free action of the piston I is the revolving cylinder outside the casing F. This cylinder revolves on its own axis. The paper on which the diagram is to be taken is fixed around this cylinder, and held in its place by the clip J. On the bottom of the cylinder there is a cord round the pulley R, which, after passing over the swivel pulley A, is then attached to the radius-bar of the Engine. It will be obvious that the traverse of the radius-bar will pull the cylinder so far round as the string thus travels. On the relaxation of the string, caused

by the descent of the Engine piston, the pulley will again take up the cord, because an internal spring, similar to the spring of a self-winding-up measuring tape, is enclosed in the revolving cylinder. The traverse of the radius-bar pulls the cylinder one way round, and the spring the other. By means of the cord attached to the radius-bar of the Engine, there is thus produced a regular traversing motion of the cylinder I; and as the pencil presses at the same time against the paper affixed to the cylinder, and also moves up and down with the *Indicator* piston,—which piston is propelled by the same force as the Engine piston—the pencil will describe a diagram according to the circumstances. The area of the cylinder of the *Indicator* is a quarter of a square inch; and each tenth of an inch on the index represents 1lb pressure to the square inch on the piston of the Engine. The spring S, compressed, shows the steam pressure; distended, it shows the atmospheric pressure upon the piston of the *Indicator* caused by the formation of the vacuum in the Engine cylinder, varying in accordance with the pressure of the uncondensed steam left in the cylinder. This spring is so adjusted as to meet the requirements of the pressure as it increases. When the steam exceeds 25lbs to the square inch above the pressure of the atmosphere, there is an additional spring enclosed in a case for higher pressures, up to 75lbs to the square inch—or for a still further increased pressure, if required—which is to be screwed on to the top of the casing F. This additional spring is represented at M. The piston-rod of the *Indicator* passes up the centre of the spring M, when it is fixed on the top of the casing F, and comes in contact with the top attached to the second spring—so that instead of the resistance of only one, there is the resistance of two springs for high-pressure steam. On the scale E for high pressure, the distances are marked thirty to the inch for steam above 25lbs, one-thirtieth of an inch representing 1lb pressure to the square inch on the steam side. The scale on the vacuum side is ten to the inch: or one-tenth of an inch represents 1lb pressure to the square inch, whether with high or low-pressure steam. It should be borne in mind that whatever may be the pressure of the steam, high or low, when the Engine is a Non-condensing or High-pressure Engine, the vacuum side of the *Indicator* is not required.

Means must be adopted to get the proper extent of traverse of the cylinder I. If the Engine be of the Horizontal or Cross-head kind, sometimes a lever is affixed to the cross-head of the piston, and the string from the *Indicator* attached to that lever at the requisite distance for the traverse required. Sometimes a stand with a moveable pulley is fixed to the Engine cylinder-cover by one of the bolts, to carry the string from the radius bar of the Engine to any part of the cylinder where the

Indicator may be fixed. With a Beam Engine, however, the *Indicator* is best fixed under the radius bar into a proper tap made for the purpose, screwed into the cover, or the bottom, of the Engine cylinder, where it can remain as a fixture ready for use at any time. For Locomotive Engines another and larger pulley may be attached, the circumference of which should be equal to the length of the stroke of the piston. The string may in that case be fixed direct to the cross-head or slide of the piston rod. The large pulley on the barrel of the *Indicator* will give out a sufficient length of string for one stroke of the Engine.

For Engines working at higher pressures than 75lbs, say as high as 250lbs per square inch, the *Indicator* is provided with another spring similar to the 75lb spring, and attached to the instrument in the same manner. Each case enclosing the spring to be used has marked on the outside the amount of pressure the spring will work up to. The measuring scale accompanying the *Indicator* is also so marked, that any figure taken by any of the three springs can be measured by it; thus dispensing with more than one portable scale. The 25lb spring is at all times a fixture, enclosed in the barrel of the instrument. The other springs require to be attached to the provision made at the uppermost part of the instrument for them.

HOW TO AFFIX AND USE THE INDICATOR.

Be particular before using the *Indicator* that the parts are well cleaned—that the piston of the instrument freely vibrates in the cylinder —and that all the working parts are carefully oiled with clean sperm oil. If the instrument be new, let it be worked a few days on the Engine, and be well oiled and cleaned three or four times each day. To affix it, first screw the plug of the *Indicator* into the grease-tap, or into a tap in the cylinder cover provided for the purpose: or to the bottom of the cylinder, into a tap there inserted. The *Indicator* will work horizontally as well as perpendicularly. When the plug or tap is thus fixed, open the tap, and blow the steam through, so that any dirt which may have accumulated may be blown away, instead of being sent into the cylinder of the instrument. Then screw the *Indicator* on to the plug, or tap. Take one end of the string which is wound round the grove of the pulley on the bottom of the revolving cylinder, and connect it with a string on the radius bar of the Engine, if it be a Beam Engine. If a Marine Engine, or Cross-head Engine, attach to some convenient part which will give the string the requisite traversing motion, which must be from the direct action of the stroke, or the piston's traverse. The string must be so adjusted as to pull round the cylinder of the *Indicator* only about

three-fourths of a revolution. There is a stop or catch to prevent the cylinder being pulled round too far. On the string to be attached to the radius bar, there is a small brass plate, called a running loop. By pulling this loop backward or forward, the proper length of the string may be easily obtained, without detaching either from the Engine or the *Indicator*. When the strings are properly adjusted, unhook them, and open the tap between the cylinder of the Engine and the cylinder of the *Indicator* to allow the *Indicator*-piston to be worked a few strokes, so that the temperature of the cylinder of the instrument may be raised to that of the Engine cylinder. Then affix the paper round the moveable cylinder. When the paper is properly affixed, close the tap previously opened. The piston of the *Indicator* will then settle with the index or pointer opposite the atmospheric line 0. Put down the pencil upon the paper, taking care that the pencil does not press too much on the paper fixed on the cylinder. By means of the adjusting screw of the pencil-holder, the required amount of pressure upon the paper can be obtained to trace the diagram. When all else is ready, connect the two strings together by the hooks on each end. The traverse of the string attached to the radius bar of the Engine, will pull the revolving cylinder as far round as has been arranged for ; and its own internal spring will cause it to recede back again with the return stroke of the Engine. During these motions the pencil will make a line on the paper round the cylinder. This line is called the atmospheric line. When that line is well defined, open the tap gently, so as to make a connection between the cylinder of the Engine and the cylinder of the *Indicator*. The piston of the *Indicator* will then partake of the motion, and travel up and down with the piston of the Steam Engine, each stroke of the *Indicator* being exactly that of the stroke of the Engine—both being propelled by the same force. By these motions a diagram will be traced on the paper of the revolving cylinder by the pencil. Then shut the tap and disconnect the cord. Take off the paper, and the diagram will be found delineated thereon. By the aid of the scale sent with the *Indicator*, or the one affixed to the instrument, or by means of a common rule, the distances on the diagram from the atmospheric line on the steam side can be measured, which will give the exact pressure of steam per square inch upon the piston of the Engine. Pursue the same means with the vacuum side of the diagram, and the amount of vacuum obtained, and also the quantity of uncondensed steam left in the cylinder, will be ascertained.

Thus, every change and every deviation of the Engine will be exhibited, including those of expansion, lead, traverse of the valve, and closing of the exhaust. Expansion produces, to all appearance, an irregular or defective diagram (see Diagram No. 19) ; but this is not the case,

because the diminished pressure of the steam at the end of the stroke, or at the termination of the piston's descent, is much below the pressure of the atmosphere, thereby reducing the steam to a low degree, which is more than compensated by the saving of fuel. A very little lead of the valve is required if the pressure be high. A diagram with the steam corner rounded shows the valve to have little or no lead, the steam being admitted upon the piston easily. A diagram square and pointed shows the valve to have too much lead,—that it opens too quickly, admitting the steam upon the piston with too great a force before the crank is in a proper position to receive it. This will in most cases cause the Engine to tremble, and, by consequence, the *Indicator* also. Too much rounded at the commencement of the exhaust corner shows also a defect for want of lead, or a quicker opening of the valve, or longer traverse of the valve on the exhaust side. In a great many instances the steam passages are too small. When that is the case, the exhaust valve ought to be fully open when the crank is at the plumb centre. If the diagram be square at the termination of the exhaust, the valve closes too late. It would be better for the Engine were the valve to close sooner, more particularly if the speed of the Engine be great. Then the diagram would show a rounding at the bottom corner (see Diagram No. 19). This is important for the steady working of the Engine—preventing, in many instances, a rapping noise in the centres, which is often mistaken for loose cotters, or steps. The closing of the exhaust before the termination of the stroke, is called "cushioning the piston." This will have to be regulated according to the speed of the Engine. The exhaust should be closed when the piston has to travel one-tenth the length of the entire stroke. The piston and most of the working parts of an Engine having to be reversed, require to be brought to a stand before the return stroke. The steam left in the cylinder will be compressed, and check the speed of the piston at the end of the stroke. The elasticity of the compressed steam between the bottom or the top of the cylinder and the piston, is ready, by its force, to commence the return stroke with ease, preventing an undue strain upon the Engine. The steam side of the valve does not require to be as forward as when the exhaust is open the full length of the stroke, because the compressed steam between the piston and the top or bottom of the cylinder will act with a force according to its compression on the return stroke. For a very quick speed of the piston, the opening on the steam side requires to be earlier, and as much steam admitted before the stroke is completed as will check the speed, and act as a cushion or buffer to the piston. If the valve be of the D kind, or if a tappet valve, it should be constructed so as to admit the steam on easy, before the valve opens full port. The Engine will in that case work much steadier—with less

strain upon it. When the steam side of the valve has too much lead—a serious defect, which has already been noticed—a rapping takes place. This is too often the result of imperfect valve-setting, and causes the *Indicator* to rebound by the suddenness of the pressure upon the piston, giving to the diagram an irregular line on the steam side. This irregularity is too often attributed to defection in the instrument, instead of the real cause, viz.:—too much lead of the valve, and opening too quickly. In the working of an Engine, and in the taking of a diagram, care should be exercised to ascertain whether any defect of this kind exists, or an erroneous conclusion from the appearance of the diagram may be the result.

We fearlessly assert, that if either the Manchester, or any other Association, continue to work to the indications given by such a class of instrument as they have hitherto employed, they are liable to serious mistakes, particularly where high-pressure steam is used. And then, the system adopted may be objected to on principle. "Office-Engineering" has not brought the Steam Engine to its present state of efficiency; nor has the cotton manufacture grown to its present national importance under red tapism, or official routine. It has acquired its status by fair, free, and unshackled competition, independently of all "authority"; and if the continued progress of the Steam Engine is desirable and worthy of being promoted, that progress can only be secured by Engineers remaining free from divided responsibility—the industrious Engineer left at liberty to apply correct principles to sound practice without the fear or favour of official prejudice.

On the occasion of a recent vacancy for the Chief-Inspectorship of the Manchester Association, Mr. EDWARD INGHAM, of Oldam, a practical Engineer, was one of three candidates selected by the Committee as most eligible for the office, and, we believe, was placed second in the vote. The following letter received from him, treating upon this branch of our subject, we here give, as corroberative of the remarks made:—

"*Croft Bank Mills, Oldham, Oct. 20th*, 1857.

"Mr. HOPKINSON:

"SIR,—Last night, in our Lecture-room, we had a most interesting discussion on the comparative merits and demerits of 'McNAUGHT'S *versus* HOPKINSON'S *Indicator*.' I endeavoured to shew that most of the objections raised against HOPKINSON'S were based upon prejudice and false notions. I told them how I myself had been deceived with respect to the weight and area of the piston; how you had kindly and lucidly explained to me the fallacy of those notions; and how we were all of us apt to form erroneous notions when led by the judgment of others, without examining for ourselves. I was surprised to find that many in our Association had long entertained correct notions with respect to the sensitiveness of your *Indicator*, but had not had the moral courage to enunciate their views in opposition to currently received notions, until some one, upon

whose authority they placed some little weight, had the courage to express similar views to their own. The moment some one whom they durst venture to chime in with, advanced similar ideas to those they had entertained for a long time, they began to give vent to their pent-up feelings, which before they durst not even moot, because different to the views entertained by the majority. I assure you we had a large number present who for a considerable length of time have looked upon your *Indicator* as giving a truer index of the internal workings of the Steam Engine than any other. I hope you will send me your work as early as conveneint; I shall then, perhaps, be able to discover some other important features, upon which I and the rest of my fellow Engineers may have entertained somewhat mistaken notions.

"I am,

"Yours most respectfully,

"EDWARD INGHAM."

We have often been called in to deal with cases where the Engines have been labouring under difficulties. One instance was at Messrs. ADSHEAD BROTHERS, at Staleybridge. Here we found the Engines labouring under extraordinary difficulties—60lbs pressure upon the piston, and a lifting at the centres sufficient to break the Engines down. After indicating, and comparing diagrams with those sent in by the Manchester Association, we found that those taken by the larger and more sensitive instrument were just the reverse of the diagrams of the Association, as it regarded the working of the Engines and the setting of the valves. The cause of the tremendous strain on the Engine was at once made apparent by the large *Indicator*. The valves were re-set, and the Engines are now in proper working order.

In very many instances we have demonstrated the superiority of the larger and more sensitive instrument, as a real *Indicator*, to that of the construction used by the Manchester Association. We have proved this by altering the Engines, showing the Engineers the various stages of the process—taking diagrams at each slight alteration—until the Engines were brought, so far as regards their working, into a state of comparative perfection: showing also, at the same time, that the small *Indicator* would not indicate the difference of the changes made. The American *Indicator* is of even worse construction than that used by the Manchester Association.

APPENDIX:

CONTAINING

TABLES AND OTHER INFORMATION CALCULATED

TO BE OF SERVICE TO

ENGINEERS AND OTHERS ENTRUSTED WITH THE

MANAGEMENT OF THE STEAM ENGINE.

TABLE.

EXPANSION OF AIR BY HEAT:

SHOWING THE INCREASE OF BULK IN PROPORTION TO THE INCREASE OF TEMPERATURE.

Fahrenheit.		Bulk.	Fahrenheit.		Bulk.
Temp. 32	Freezing Point	1000	Temp. 75	... ...	1099
— 33	... ...	1002	— 76	Summer Heat	1101
— 34	... ...	1004	— 77	... ...	1104
— 35	... ...	1007	— 78	... ...	1106
— 36	... ...	1009	— 79	... ...	1108
— 37	... ...	1012	— 80	... ...	1110
— 38	... ...	1015	— 81	... ...	1112
— 39	... ...	1018	— 82	... ...	1114
— 40	... ...	1021	— 83	... ...	1116
— 41	... ...	1023	— 84	... ...	1118
— 42	.. ...	1025	— 85	... ...	1121
— 43	... ...	1027	— 86	... ...	1123
— 44	... ...	1030	— 87	... ...	1125
— 45	... ...	1032	— 88	... ...	1128
— 46	... ...	1034	— 89	... ...	1130
— 47	... ...	1036	— 90	... ...	1132
— 48	... ...	1038	— 91	... ...	1134
— 49	... ...	1040	— 92	... ..	1136
— 50	... ...	1043	— 93	.. ...	1138
— 51	... ...	1045	— 94	... ...	1140
— 52	... ...	1047	— 95	... ..	1142
— 53	... ...	1050	— 96	Blood Heat	1144
— 54	... ...	1052	— 97	... ...	1146
— 55	... ...	1055	— 98	... ...	1148
— 56	Temperate	1057	— 99	... ...	1150
— 57	... ...	1059	— 100	... ...	1152
— 58	... ...	1062	— 110	Fever Heat 112	1173
— 59	... ...	1064	— 120	... ...	1194
— 60	... ...	1066	— 130	... ...	1215
— 61	... ...	1069	— 140	... ...	1235
— 62	... ...	1071	— 150	... ...	1255
— 63	... ...	1073	— 160	... ...	1275
— 64	... ...	1075	— 170	Spirits Boil 176	1295
— 65	... ...	1077	— 180	... ...	1315
— 66	... ...	1080	— 190	... ...	1334
— 67	... ...	1082	— 200	... ...	1364
— 68	... ...	1084	— 210	... ...	1372
— 69	... ...	1087	— 212	Water Boils	1375
— 70	... ...	1089	— 302	... ...	1558
— 71	... ...	1091	— 392	... ...	1739
— 72	... ...	1093	— 482	... ...	1919
— 73	... ...	1095	— 572	... ...	2098
— 74	... ...	1097	— 680	... ...	2312

IMPERIAL STANDARD MEASURES.

1.—MEASURE OF LENGTH.

12	inches	1	foot.							
36	„	3	„	1	yard.					
198	„	16½	„	5½	„	1	pole or perch.			
7920	„	660	„	220	„	40	„	1	furlong.	
63360	„	5280	„	1760	„	320	„	8	„	1 English mile.
				2240	„					1 Irish „
				1984	„					1 Scotch „

SPECIAL MEASURES OF LENGTH.

Nautical Measure.	*Land Measure.*
1 nautical mile ... 6082·66 feet.	7·92 inches..... 1 link.
3 miles ..... 1 league.	100 links ..... 1 chain.
20 leagues ..... 1 degree.	80 chains ..... 1 mile.
360 degrees = earth's circumference	69·121 miles ..... 1 geo. deg.

6 feet = 1 fathom—used in measuring ropes, chains, &c.

2.—MEASURE OF CAPACITY.

General Measure of Solidity.

1728	cubic inches	1 cubic foot.
27	cubic feet	1 cubic yard.
42	cubic feet	1 ton of shipping.

3.—IMPERIAL GALLON MEASURE FOR LIQUIDS, CORN, &c.

WATER. Cubic Inches.	lbs. av.											
8·665	$\frac{5}{16}$	1	gill.									
34·659	1¼	4	„	1	pint.							
69·818	2½	8	„	2	„	1	quart.					
277·274	10	32	„	8	„	4	„	1	gallon.			
554·548	20	64	„	16	„	8	„	2	„	1	peck.	
2218·19	80	256	„	64	„	32	„	8	„	4	„	1 bush.
17745·5	640	2048	„	512	„	256	„	64	„	32	„	8 1 qr.

1	gallon of	sea water	weighs	10·32lbs	avoirdupois.
1	„	oil	„	9·32	„
1	„	proof spirits	... ...	9·3	„

Thirty-two gallons of proof spirits in winter will, without being diluted, measure thirty-three in summer.

All fluids expand with heat, and contract with cold down to 40 degrees, but expand when freezing. 32, freezing point; 56, temperate heat; 76, summer heat; 96, blood heat; 112, fever heat; 176, spirits of wine boil; 212, water boils, when the pressure of the atmosphere is 15lbs to the square inch; if the pressure be less, water boils at a less temperature.

These temperatures are Fahrenheit, by which we are guided in England. The centrigrade rule is used in France, where the freezing point is zero, or 0, and the boiling point 100°. Reaumur's rule is used by many continental nations—freezing point, or zero, 0, and boiling point 80.

4.—TROY WEIGHT.

24	grains	1	pennyweight.					
480	„	20	„	1	ounce.			
5760	„	240	„	12	„	1	pound.	

By this weight are weighed gold, silver, jewels, electuaries, and all liquors.

The standard for gold coin is 22 carats of fine gold and two carats of copper melted together. For silver, 11 oz. 2 dwts. of fine silver, and 18 dwts. of copper.

100lbs 1 cwt. 20 cwt. 1 ton of gold or silver.

To reduce pounds troy into avoirdupois, multiply by 144, and divide by 175, the quotient will be the number of pounds avoirdupois.

5.—AVOIRDUPOIS WEIGHT.

16	drams	1	ounce.								
256	„	16	„	1	pound.						
3584	„	224	„	14	„	1	stone.				
7168	„	448	„	28	„	2	„	1	quarter.		
28672	„	1792	„	112	„	8	„	4	„	1	cwt.
573440	„	35840	„	2240	„	160	„	80	„	20	„ 1 ton.

A keel of coal at Newcastle is 21 tons 4 cwt., and a chaldron is 53 cwt. A chaldron of coal in London is 28½ cwt.

About 426	cubic inches of cast iron	... ...	1 cwt.
8520	„ or nearly 5 cubic feet	...	1 ton.
13	cublic feet of stone	... ...	1 „
23	„ sand	... ...	1 „
29	„ coal	... ...	1 „
38	„ tallow	... ...	1 „
39	„ oil	... ...	1 „
40	„ rough timber	...	1 „
50	„ squared timber	...	1 „

6.—MEASURE OF SURFACES.

144	inches	1	square foot.								
1296	„	9	„	1	square yard.						
39204	„	272¼	„	30¼	„	1	square pole.				
1568160	„	10890	„	1210	„	40	„	1	rood.		
6272640	„	43560	„	4840	„	160	„	4	„	1	acre.

By this measure are measured all things that have length and breadth, such as land, painting, plastering, flooring, thatching, plumbing, glazing, &c.

RULE TO ASCERTAIN THE WEIGHT OF CAST-IRON BALLS OF ANY DIAMETER.

Cube the diameter, and divide by 7·27. The quotient is the weight.

EXAMPLE : 9 inches diameter.

9

81

9

7·27) 729·00 (100 $\frac{2}{7.27}$ lbs.

727 · ·

2·00

BOILING POINT OF WATER,

UNDER DIFFERENT PRESSURES OF THE ATMOSPHERE.

Barometer.		Pressure.		Boiling Point.	
26	inches	13lbs per square inch		205	degrees.
26½	„	13¼	„	205¾	„
27	„	13½	„	206¾	„
27½	„	13¾	„	207½	„
28	„	14	„	208½	„
28½	„	14¼	„	209¼	„
29	„	14½	„	210¼	„
29½	„	14¾	„	211	„
30	„	15	„	212	„
30½	„	15¼	„	212¾	„
31	„	15½	„	213¾	„

Water in vacuum boils at about 98 degrees Fahrenheit, and assumes a solid at 32 degrees in the atmosphere, when it expands $\frac{1}{17}$th its original bulk. At a temperature of 212 degrees it becomes vapour, or steam, nor can that temperature be increased in an open vessel. In a closed one it may be heated to redness. Mercury will fall $\frac{1}{10}$th of an inch for every 100 feet perpendicular height. In ascending Snowden, in North Wales, the mercury fell $3\frac{3}{10}$ths inches, 3,720 feet above the sea. The velocity of wind in a strong gale is 30 to 35 miles per hour; hard gale, 40 to 45; storm, 50 to 55; and a hurricane, 80 to 100 miles per hour.

GEOMETRY.

45 degrees ... ⅛ of a circle.
90 „ ... 1 quadrant, or quarter of a circle.
360 „ ... 1 circle. When divided into part, are called degrees.

Many calculations are founded on this division of the circle.

TABLES OF WEIGHTS.

Weight of Cast-iron Balls from 3 to 13 inches in diameter. Useful for Safety Valves, &c.

Diameter in Inches...	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7
Weight in lbs.	3¾	4¾	5¾	7¼	8¾	10½	12½	14¾	17	20	23	26	29¾	33½	37¾	42¼	47¼

Diameter in Inches...	7¼	7½	7¾	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11½
Weight in lbs.	52½	58	64	70½	77¼	84½	92¼	100¼	109	118	127½	137¾	148¼	159½	171	183¼	209½

Diameter in Inches...	12	13															
Weight in lbs.	238	302															

Weight of Cast-iron Plates per superficial foot as per Thickness.

Thickness in Inches	⅛	¼	⅜	½	⅝	¾	⅞	1
Weight	lb oz 4 13	lb oz 9 10	lb oz 14 8	lb oz 19 5	lb oz 24 2	lb oz 29 0	lb oz 33 13	lb oz 38 10

Weight of Boiler Plates 1 foot square, and from $\frac{1}{16}$th of an inch Thick.

Thickness in Inches	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
Weight in lbs per foot square...	$2\frac{1}{2}$	5	$7\frac{1}{2}$	10	$12\frac{1}{2}$	15	$17\frac{1}{2}$	20	$22\frac{1}{2}$	25	$27\frac{1}{2}$	30	$32\frac{1}{2}$	35	$37\frac{1}{2}$	40

Weight of Square Bar-iron, from $\frac{1}{2}$ an inch to 6 inches square, 1 foot long.

For Calculating the Weight of Shafting, &c.

Square	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$
Weight in lbs	$\frac{8}{10}$	$1\frac{1}{4}$	2	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$7\frac{1}{2}$	9	$10\frac{1}{2}$	12	$13\frac{1}{2}$	$15\frac{1}{4}$	17	19	21

Square	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4	$4\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{3}{8}$	$4\frac{1}{2}$	$4\frac{5}{8}$
Weight in lbs.....	$23\frac{1}{4}$	$25\frac{1}{2}$	28	$30\frac{1}{2}$	33	$35\frac{3}{4}$	$38\frac{1}{2}$	$41\frac{1}{2}$	$44\frac{1}{2}$	$47\frac{1}{2}$	$50\frac{3}{4}$	54	$57\frac{1}{2}$	61	$64\frac{3}{4}$	$68\frac{1}{2}$	$72\frac{1}{4}$

Square	$4\frac{3}{4}$	$4\frac{7}{8}$	5	$5\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{3}{4}$	6										
Weight in lbs	$76\frac{1}{4}$	$80\frac{1}{4}$	$84\frac{1}{2}$	$93\frac{1}{4}$	$102\frac{1}{4}$	$111\frac{3}{4}$	$121\frac{3}{4}$										

Weight of Round Bar-iron, from ½ an inch to 6 inches Diameter, 1 foot long.

For Calculating the Weiyht of Shafting, &c.

Diameter in Inches...	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2	2⅛	2¼	2⅜	2½
Weight in lbs.....	¾	1	1½	2	2¾	3½	4¼	5	6	7	8	9¼	10½	12	13½	15	16¾

Diameter in Inches...	2⅝	2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜	4½	4⅝
Weight in lbs.....	18¼	20	22	24	26	28	30¼	32½	35	37¼	40	42½	45¼	48	50¾	53¾	56¾

Diameter in Inches	4¾	4⅞	5	5¼	5½	5¾	6										
Weight in lbs	60	63	66¾	73¼	80¼	87¾	95½										

Weight of Sheet Lead per superficial foot, as per Thickness.

Thickness in Inches	1/16	1/12	1/10	1/8	1/6	1/5	1/4	1/3	1/2	3/4	1
Weight in lbs	3¼	5	6	7½	10	12	14¾	19¾	29½	44¼	59

Weight of Cast-iron Pipes 1 foot in length, from $\frac{1}{4}$ inch to $1\frac{1}{4}$ inch thick, and from 3 to 24 inches Diameter.

Diameter of Bore in Inches.	THICKNESS IN INCHES.								
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
3	$8\frac{1}{2}$	$12\frac{1}{2}$	$17\frac{1}{4}$	$22\frac{1}{4}$	$27\frac{1}{2}$				
$3\frac{1}{2}$	$9\frac{1}{4}$	$14\frac{1}{4}$	$19\frac{1}{2}$	$25\frac{1}{4}$	$31\frac{1}{4}$				
4	10	$16\frac{3}{4}$	22	$28\frac{1}{2}$	35				
$4\frac{1}{2}$	$11\frac{3}{4}$	18	$24\frac{1}{2}$	$31\frac{1}{2}$	$38\frac{3}{4}$				
5	13	$19\frac{3}{4}$	27	$34\frac{1}{2}$	$42\frac{1}{4}$	$50\frac{1}{2}$	59		
$5\frac{1}{2}$	15	$21\frac{1}{2}$	$29\frac{1}{2}$	$37\frac{1}{2}$	46	$54\frac{3}{4}$	$63\frac{3}{4}$		
6		$23\frac{1}{2}$	32	$40\frac{3}{4}$	$49\frac{3}{4}$	59	$68\frac{3}{4}$	$78\frac{3}{4}$	$88\frac{3}{4}$
$6\frac{1}{2}$		$25\frac{1}{4}$	$34\frac{1}{2}$	$43\frac{3}{4}$	$53\frac{1}{2}$	$63\frac{1}{2}$	$73\frac{1}{2}$	$84\frac{1}{4}$	95
7		$27\frac{1}{4}$	$36\frac{3}{4}$	$46\frac{3}{4}$	$56\frac{3}{4}$	$67\frac{3}{4}$	$78\frac{1}{2}$	$89\frac{3}{4}$	$101\frac{1}{4}$
$7\frac{1}{2}$		29	39	50	$60\frac{3}{4}$	72	$83\frac{1}{2}$	$95\frac{1}{4}$	$107\frac{1}{2}$
8		$30\frac{3}{4}$	$41\frac{3}{4}$	53	$64\frac{1}{2}$	$76\frac{1}{4}$	$88\frac{1}{2}$	$100\frac{3}{4}$	$113\frac{1}{2}$
$8\frac{1}{2}$		33	$44\frac{1}{2}$	$56\frac{1}{4}$	$68\frac{1}{4}$	$80\frac{3}{4}$	$93\frac{1}{2}$	$106\frac{1}{2}$	120
9		$34\frac{1}{2}$	$46\frac{1}{2}$	59	$71\frac{3}{4}$	$84\frac{3}{4}$	$98\frac{1}{2}$	$111\frac{3}{4}$	$125\frac{3}{4}$
$9\frac{1}{2}$		$36\frac{1}{4}$	49	62	$75\frac{1}{2}$	89	103	$117\frac{1}{2}$	132
10		$38\frac{1}{4}$	$51\frac{1}{2}$	$65\frac{1}{4}$	$79\frac{1}{4}$	$93\frac{1}{2}$	108	$122\frac{3}{4}$	138
$10\frac{1}{2}$			54	$68\frac{1}{4}$	$82\frac{3}{4}$	$97\frac{3}{4}$	$112\frac{3}{4}$	$128\frac{1}{2}$	$144\frac{1}{4}$
11			$56\frac{1}{2}$	$71\frac{1}{4}$	$86\frac{1}{2}$	102	$117\frac{3}{4}$	134	$150\frac{1}{4}$
$11\frac{1}{2}$			59	$76\frac{1}{4}$	90	$106\frac{1}{4}$	$122\frac{3}{4}$	$139\frac{1}{2}$	$156\frac{1}{2}$
12			$61\frac{1}{4}$	$77\frac{1}{2}$	$93\frac{1}{2}$	$110\frac{1}{2}$	$127\frac{1}{2}$	145	$162\frac{1}{2}$
13				$82\frac{3}{4}$	$101\frac{1}{4}$	$118\frac{1}{4}$	$137\frac{1}{2}$	154	$173\frac{1}{2}$
14				$89\frac{1}{4}$	$108\frac{1}{4}$	$126\frac{1}{2}$	$146\frac{1}{4}$	$165\frac{1}{4}$	$185\frac{1}{4}$
15				$95\frac{1}{4}$	$115\frac{3}{4}$	$135\frac{1}{4}$	$156\frac{1}{4}$	$176\frac{1}{4}$	198
16					$123\frac{1}{4}$	143	166	$187\frac{1}{2}$	$211\frac{1}{4}$
17					$130\frac{1}{4}$	$152\frac{1}{2}$	$178\frac{1}{2}$	$198\frac{1}{4}$	$223\frac{1}{2}$
18					137	$161\frac{1}{4}$	$185\frac{1}{4}$	209	$235\frac{1}{4}$
19						$169\frac{1}{4}$	$195\frac{3}{4}$	$222\frac{1}{4}$	247
20						178	$205\frac{1}{4}$	$233\frac{1}{4}$	259
21							214	$243\frac{1}{2}$	$273\frac{1}{4}$
22							$223\frac{1}{2}$	$254\frac{3}{4}$	$285\frac{1}{4}$
23							$233\frac{1}{2}$	$265\frac{1}{2}$	$298\frac{1}{4}$
24							$245\frac{1}{4}$	$277\frac{1}{2}$	$310\frac{1}{2}$

WEIGHT OF MATERIALS.

	Weight of a cubic foot in lbs.	Weight of a cubic inch in ozs.	No. of cubic inches in a lb.	Weight of a cubic inch in lbs.
Mercury	848	7·851	2·037	·4908
Lead	709	6·456	2·437	·4103
Bar Iron	477	4·140	3·623	·276
Cast Iron	454½	4·203	3·802	·263
Sheet Copper ...	557¼	5·159	3·103	·3225
Cast Copper.....	549¼	5·086	3·146	·3178
Cast Brass	524¾	4·852	3·223	·3037
Brick	125	1·456	13·824	·0723
Stone	151	1·396	11·443	·0873
Water	62½		27½	

Thirty-six feet of common water make 1 ton. 35 feet of sea water make 1 ton.

One cubic foot of water = 6¼ imperial gallons, or 62½lbs. 1 cylindrical foot = 5 gallons, or 49lbs.

11·2 imperial gallons = 1 cwt. 224 imperial gallons = 1 ton. 1 gallon of fresh water = 10lbs. 1 gallon of sea water = 10¼lbs.

At a temperature of 62° Fahrenheit, between 62° and 42°, water attains its greatest density; and the pressure is as the perpendicular height, independent of quantity.

Water is not compressible. It presses in every direction, and finds a level; thus, a small quantity will balance and support a great quantity, whatever the difference in dimension.

The centre of the pressure of a column of water is two-thirds of its depth from the surface.

Ten pounds of distilled, or rain, water equals the standard gallon at 62°.

2·004	inches of a column of	mercury ...	...	1lb.
27·648	„ „	water ...	...	1lb.
26·895	„ „	sea water ...	...	1lb.

A TABLE SHOWING THE DIFFERENCE IN THE STRENGTH OF METALS.

Wrought Iron	1000	Gold	273
Copper	550	Zinc	199
Platinum	494	Tin	63
Silver	349	Lead	50

A copper bolt or rod of the same thickness as iron, will sustain little more than one-half the weight iron will. Iron-wire one-sixteenth of an inch diameter is capable of sustaining a weight of 500lbs. A bar of wrought iron one inch square, when sound and good, will require 25 tons to pull it asunder.

HEAT-CONDUCTING POWERS OF DIFFERENT METALS.

Gold	1000	Iron	374
Silver	973	Zinc	368
Copper	898	Tin	304
Platinum	391	Lead	108

A TABLE SHOWING THE TEMPERATURE METALS MELT AT.

	Degrees.		Degrees.
Gold	2016	Lead	612
Platinum	3280	Tin	442
Silver	1873	Zinc	773
Copper	1996	Cast Iron	2786
Brass	1900	Mercury boils	672

Tin 2 parts, Lead 2 parts, mixed, melts at 332°.

With Cast-iron, melted from the pig, its strength may be represented by 1; the second time by $1\frac{1}{2}$; the third time by 2, and so on until it has been melted nine or ten times, when it will have attained its maximum strength—that being about four times the strength of the first casting. This shows how important it is to have all toothed wheels, particularly the first driving wheels, beams, cranks, shafts, or other parts of a Steam Engine and going gear, made from good old metal, and not new Pig-iron. By being re-melted, the metal becomes refined, closer in the pores, works smoother, and wears longer.

Metal melted in a blast furnace is not equal in strength to the same metal melted in an air furnace.

A TABLE FOR SAFETY VALVES,

CYLINDERS, AIR-PUMPS, &c.,

Containing the Circumferences and Areas of Circles from $\frac{1}{16}$ of an inch to 10 inches, advancing by $\frac{1}{16}$ of an inch; and by $\frac{1}{8}$ of an inch, from 10 inches to 100 inches Diameter.

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
$\frac{1}{16}$	.1963	.0030	2 in.	6.2832	3.1416
$\frac{1}{8}$	.3927	.0122	$\frac{1}{16}$	6.4795	3.3411
$\frac{3}{16}$	.5890	.0276	$\frac{1}{8}$	6.6759	3.5465
$\frac{1}{4}$	.7854	.0490	$\frac{3}{16}$	6.8722	3.7582
$\frac{5}{16}$	.9817	.0767	$\frac{1}{4}$	7.0686	3.9760
$\frac{3}{8}$	1.1781	.1104	$\frac{5}{16}$	7.2649	4.2001
$\frac{7}{16}$	1.3744	.1503	$\frac{3}{8}$	7.4613	4.4302
$\frac{1}{2}$	1.5708	.1963	$\frac{7}{16}$	7.6576	4.6664
$\frac{9}{16}$	1.7671	.2485	$\frac{1}{2}$	7.8540	4.9087
$\frac{5}{8}$	1.9635	.3068	$\frac{9}{16}$	8.0503	5.1573
$\frac{11}{16}$	2.1598	.3712	$\frac{5}{8}$	8.2467	5.4119
$\frac{3}{4}$	2.3562	.4417	$\frac{11}{16}$	8.4430	5.6727
$\frac{13}{16}$	2.5525	.5185	$\frac{3}{4}$	8.6394	5.9395
$\frac{7}{8}$	2.7489	.6013	$\frac{13}{16}$	8.8357	6.2126
$\frac{15}{16}$	2.9452	.6903	$\frac{7}{8}$	9.0321	6.4918
			$\frac{15}{16}$	9.2284	6.7772
1 in.	3.1416	.7854			
$\frac{1}{16}$	3.3379	.8861	3 in.	9.4248	7.0686
$\frac{1}{8}$	3.5343	.9940	$\frac{1}{16}$	9.6211	7.3662
$\frac{3}{16}$	3.7306	1.1075	$\frac{1}{8}$	9.8175	7.6699
$\frac{1}{4}$	3.9270	1.2271	$\frac{3}{16}$	10.0138	7.9798
$\frac{5}{16}$	4.1233	1.3529	$\frac{1}{4}$	10.2102	8.2957
$\frac{3}{8}$	4.3197	1.4848	$\frac{5}{16}$	10.4065	8.6179
$\frac{7}{16}$	4.5160	1.6229	$\frac{3}{8}$	10.6029	8.9462
$\frac{1}{2}$	4.7124	1.7671	$\frac{7}{16}$	10.7992	9.2806
$\frac{9}{16}$	4.9087	1.9175	$\frac{1}{2}$	10.9956	9.6211
$\frac{5}{8}$	5.1051	2.0739	$\frac{9}{16}$	11.1919	9.9678
$\frac{11}{16}$	5.3014	2.2365	$\frac{5}{8}$	11.3883	10.3206
$\frac{3}{4}$	5.4978	2.4052	$\frac{11}{16}$	11.5846	10.6796
$\frac{13}{16}$	5.6941	2.5801	$\frac{3}{4}$	11.7810	11.0446
$\frac{7}{8}$	5.8905	2.7611	$\frac{13}{16}$	11.9773	11.4159
$\frac{15}{16}$	6.0868	2.9483	$\frac{7}{8}$	12.1737	11.7932

LIBRARY OF THE UNIVERSITY

Diameter.	Circum.	Area.	Diameter.	Circum.	Area
$\frac{15}{16}$	12.3700	12.1768	$\frac{1}{2}$	20.4204	33.1831
			$\frac{9}{16}$	20.6167	33.8244
4 in.	12.5664	12.5664	$\frac{5}{8}$	20.8131	34.4717
$\frac{1}{16}$	12.7627	12.9622	$\frac{11}{16}$	21.0094	35.1252
$\frac{1}{8}$	12.9591	13.3640	$\frac{3}{4}$	21.2058	35.7847
$\frac{3}{16}$	13.1554	13.7721	$\frac{13}{16}$	21.4021	36.4505
$\frac{1}{4}$	13.3518	14.1862	$\frac{7}{8}$	21.5985	37.1224
$\frac{5}{16}$	13.5481	14.6066	$\frac{15}{16}$	21.7948	37.8005
$\frac{3}{8}$	13.7445	15.0331			
$\frac{7}{16}$	13.9408	15.4657	7 in.	21.9912	38.4846
$\frac{1}{2}$	14.1372	15.9043	$\frac{1}{16}$	22.1875	39.1749
$\frac{9}{16}$	14.3335	16.3492	$\frac{1}{8}$	22.3839	39.8713
$\frac{5}{8}$	14.5299	16.8001	$\frac{3}{16}$	22.5802	40.5469
$\frac{11}{16}$	14.7262	17.2573	$\frac{1}{4}$	22.7766	41.2825
$\frac{3}{4}$	14.9226	17.7205	$\frac{5}{16}$	22.9729	41.9974
$\frac{13}{16}$	15.1189	18.1900	$\frac{3}{8}$	23.1693	42.7184
$\frac{7}{8}$	15.3153	18.6655	$\frac{7}{16}$	23.3656	43.4455
$\frac{15}{16}$	15.5716	19.1472	$\frac{1}{2}$	23.5620	44.1787
			$\frac{9}{16}$	23.7583	44.9181
5 in.	15.7080	19.6350	$\frac{5}{8}$	23.9547	45.6636
$\frac{1}{16}$	15.9043	20.1290	$\frac{11}{16}$	24.1510	46.4153
$\frac{1}{8}$	16.1007	20.6290	$\frac{3}{4}$	24.3474	47.1730
$\frac{3}{16}$	16.2970	21.1252	$\frac{13}{16}$	24.5437	47.9370
$\frac{1}{4}$	16.4934	21.6475	$\frac{7}{8}$	24.7401	48.7070
$\frac{5}{16}$	16.6897	22.1661	$\frac{15}{16}$	24.9364	49.4833
$\frac{3}{8}$	16.8861	22.6907			
$\frac{7}{16}$	17.0824	23.2215	8 in.	25.1328	50.2656
$\frac{1}{2}$	17.2788	23.7583	$\frac{1}{16}$	25.3291	51.0541
$\frac{9}{16}$	17.4751	24.3014	$\frac{1}{8}$	25.5255	51.8486
$\frac{5}{8}$	17.6715	24.8505	$\frac{3}{16}$	25.7218	52.8994
$\frac{11}{16}$	17.8678	25.4058	$\frac{1}{4}$	25.9182	53.4562
$\frac{3}{4}$	18.0642	25.9672	$\frac{5}{16}$	26.1145	54.2748
$\frac{13}{16}$	18.2605	26.5348	$\frac{3}{8}$	26.3109	55.0885
$\frac{7}{8}$	18.4569	27.1085	$\frac{7}{16}$	26.5072	55.9138
$\frac{15}{16}$	18.6532	27.6884	$\frac{1}{2}$	26.7036	56.7451
			$\frac{9}{16}$	26.8999	57.5887
6 in.	18.8496	28.2744	$\frac{5}{8}$	27.0963	58.4264
$\frac{1}{16}$	19.0459	28.8665	$\frac{11}{16}$	27.2926	59.7762
$\frac{1}{8}$	19.2423	29.4647	$\frac{3}{4}$	27.4890	60.1321
$\frac{3}{16}$	19.4386	30.0798	$\frac{13}{16}$	27.6853	60.9943
$\frac{1}{4}$	19.6350	30.6796	$\frac{7}{8}$	27.8817	61.8625
$\frac{5}{16}$	19.8313	31.2964	$\frac{15}{16}$	27.0780	62.7369
$\frac{3}{8}$	20.0277	31.9192			
$\frac{7}{16}$	20.2240	32.5481	9 in.	28.2744	63.6174

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
1/16	28.4707	64.5041	1/8	41.2338	135.2974
1/8	28.6671	65.3968	1/4	41.6262	137.8867
3/16	28.8634	66.2957	3/8	42.0189	140.5007
1/4	29.0598	67.2007	1/2	42.4116	143.1391
5/16	29.2561	68.1120	5/8	42.8043	145.8021
3/8	29.4525	69.0293	3/4	43.1970	148.4896
7/16	29.6488	69.9528	7/8	43.5897	151.2017
1/2	29.8452	70.8823			
9/16	30.0415	71.8181	14 in.	43.9824	153.9384
5/8	30.2379	72.7599	1/8	44.3751	156.6995
11/16	30.4342	73.7079	1/4	44.7676	159.4852
3/4	30.6306	74.6620	3/8	45.1605	162.2956
13/16	30.8269	75.6223	1/2	45.5532	165.1303
7/8	31.0233	76.5887	5/8	45.9459	167.9896
15/16	31.2196	77.5613	3/4	46.3386	170.8735
			7/8	46.7313	173.7820
10 in.	31.4160	78.5400			
1/8	31.8087	80.5157	15 in.	47.1240	176.7150
1/4	32.2014	82.5160	1/8	47.5167	179.6725
3/8	32.5941	84.5409	1/4	47.9094	182.6545
1/2	32.9868	86.5903	3/8	48.3021	185.6612
5/8	33.3795	88.6643	1/2	48.6948	188.6923
3/4	33.7722	90.7627	5/8	49.0875	191.7480
7/8	34.1649	92.8858	3/4	49.4802	194.8282
			7/8	49.8729	197.9330
11 in.	34.5576	95.0334			
1/8	34.9503	97.2053	16 in.	50.2656	201.0624
1/4	35.3430	99.4021	1/8	50.6583	204.2162
3/8	35.7357	101.6234	1/4	51.0510	207.3946
1/2	36.1284	103.8691	3/8	51.4437	210.5976
5/8	36.5211	106.1394	1/2	51.8364	213.8251
3/4	36.9138	108.4342	5/8	52.2291	217.0772
7/8	37.3065	110.7536	3/4	52.6218	220.3537
			7/8	53.0145	223.6549
12 in.	37.6992	113.0976			
1/8	38.0919	115.4660	17 in.	53.4072	226.9806
1/4	38.4846	117.8590	1/8	53.7999	230.3308
3/8	38.8773	120.2766	1/4	54.1926	233.7055
1/2	39.2700	122.7187	3/8	54.5853	237.1049
5/8	39.6627	125.1854	1/2	54.9780	240.5287
3/4	40.0554	127.6765	5/8	55.3707	243.9771
7/8	40.4481	130.1923	3/4	55.7634	247.4500
			7/8	56.1561	250.9475
13 in.	43.8408	132.7326			

Diameter.	Circum.	Area.	Diameter.	Circum.	Area
18 in.	56.5488	254.4696	23 in.	72.2568	415.4766
1/8	56.9415	258.0161	1/8	72.6495	420.0049
1/4	57.8342	261.5872	1/4	73.0422	424.5577
3/8	57.7269	265.1829	3/8	73.4349	429.1352
1/2	58.1196	268.8031	1/2	73.8276	433.7371
5/8	58.5123	272.4479	5/8	74.2203	438.3636
3/4	58.9056	276.1171	3/4	74.6130	443.0146
7/8	59.2977	279.8110	7/8	75.0057	447.6992
19 in.	59.6904	283.5294	24 in.	75.3984	452.3904
1/8	60.0831	287.2723	1/8	75.7911	457.1150
1/4	60.4758	291.0397	1/4	76.1838	461.8642
3/8	60.8685	294.8312	3/8	76.5765	466.6380
1/2	61.2612	298.6483	1/2	76.9692	471.4363
5/8	61.6539	302.4894	5/8	77.3619	476.2592
3/4	62.0466	306.3550	3/4	77.7546	481.1065
7/8	62.4393	310.2452	7/8	78.1473	485.9785
20 in.	62.8320	314.1600	25 in.	78.5400	490.8750
1/8	63.2247	318.0992	1/8	78.9327	495.7960
1/4	63.6174	322.0630	1/4	79.3254	500.7415
3/8	64.0101	326.0514	3/8	79.7181	505.7117
1/2	64.4028	330.0643	1/2	80.1108	510.7063
5/8	64.7955	334.1018	5/8	80.5035	515.7255
3/4	65.1882	338.1637	3/4	80.8962	520.7692
7/8	65.5809	342.2503	7/8	81.2889	525.8375
21 in.	65.7936	346.3614	26 in.	81.6816	530.9304
1/8	66.3663	350.4970	1/8	82.0743	536.0477
1/4	66.7590	354.6571	1/4	82.4670	541.1896
3/8	67.1517	358.8419	3/8	82.8597	546.3561
1/2	67.5444	363.0511	1/2	83 2524	551.5471
5/8	67.9371	367.2849	5/8	83.6451	556.7627
3/4	68.3298	371.5432	3/4	84.0378	562.0027
7/8	68.7225	375.8261	7/8	84.4305	567.2674
22 in.	69.1152	380.1336	27 in.	84.8232	572.5566
1/8	69.5079	384.4655	1/8	85.2159	577.8703
1/4	69.9006	388.8220	1/4	85.6086	583.2085
3/8	70.2933	393.2031	3/8	86.0013	588.5714
1/2	70.6860	397.6087	1/2	86.3940	593.9587
5/8	71.0787	402.0388	5/8	86.7867	599.3706
3/4	71.4714	406.4935	3/4	87.1794	604.8070
7/8	71.8641	410.9728	7/8	87.5721	610.2680

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
28 in.	87.9648	615.7536	33 in.	103.6728	855.3006
1/8	88.3575	621.2636	1/8	104.0655	861.7924
1/4	88.7502	626.7982	1/4	104.4582	868.3087
3/8	89.1429	632.3574	3/8	104.8509	874.8497
1/2	89.5356	637.9411	1/2	105.2436	881.4151
5/8	89.9283	643.5494	5/8	105.6363	888.0051
3/4	90.3210	649.1821	3/4	106.0290	894.6196
7/8	90.7137	654.8395	7/8	106.4217	901.2587
29 in.	91.1064	660.5214	34 in.	106.8144	907.9224
1/8	91.4991	666.2278	1/8	107.2071	914.6105
1/4	91.8918	671.9587	1/4	107.5998	921.3232
3/8	92.2845	677.7143	3/8	107.9925	928.0605
1/2	92.6772	683.4943	1/2	108.3852	934.8223
5/8	93.0699	689.2989	5/8	108.7779	941.6086
3/4	93.4626	695.1280	3/4	109.1706	948.4195
7/8	93.8553	700.9817	7/8	109.5633	955.2550
30 in.	94.2480	706.8600	35 in.	109.9560	962.1150
1/8	94.6407	712.7627	1/8	110.3487	968.9995
1/4	95.0334	718.6900	1/4	110.7414	975.9085
3/8	95.4261	724.6419	3/8	111.1341	982.8422
1/2	95.8188	730.6183	1/2	111.5268	989.8003
5/8	96.2115	736.6193	5/8	111.9195	996.7830
3/4	96.6042	742.6447	3/4	112.3122	1003.7902
7/8	96.9969	748.6948	7/8	112.7049	1010.8220
31 in.	97.3896	754.7694	36 in.	113.0976	1017.8784
1/8	97.7823	760.8685	1/8	113.4903	1024.9592
1/4	98.1750	766.9921	1/4	113.8830	1032.0646
3/8	98.5677	773.1404	3/8	114.2757	1039.1946
1/2	98.9684	779.3131	1/2	114.6684	1046.3941
5/8	99.3531	785.5104	5/8	115.0611	1053.5281
3/4	99.7458	791.7322	3/4	115.4538	1060.7317
7/8	100.1385	797.9786	7/8	115.8465	1067.9599
32 in.	100.5312	804.2496	37 in.	116.2392	1075.2126
1/8	100.9240	810.5450	1/8	116.6319	1082.4898
1/4	101.3166	816.8650	1/4	117.0246	1089.7915
3/8	101.7093	823.2096	3/8	117.4173	1097.1179
1/2	102.1020	829.5787	1/2	117.8100	1104.4687
5/8	102.4947	835.9724	5/8	118.2027	1111.8441
3/4	102.8874	842.3905	3/4	118.5954	1119.2440
7/8	103.2801	848.8333	7/8	118.9881	1126.6685

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
38 in.	119.3808	1134.1176	43 in.	135.0888	1452.2046
1/8	119.7735	1141.5911	1/8	135.4815	1460.6599
1/4	120.1662	1149.0892	1/4	135.8742	1469.1397
3/8	120.5589	1156.6119	3/8	136.2669	1477.6342
1/2	120.9516	1164.1591	1/2	136.6596	1486.1731
5/8	121.3443	1171.7309	5/8	137.0523	1494.7266
3/4	121.7370	1179.3271	3/4	137.4450	1503.3046
7/8	122.1297	1186.9480	7/8	137.8377	1511.9072
39 in.	122.5224	1194.5934	44 in.	138.2304	1520.5341
1/8	122.9151	1202.2633	1/8	138.6231	1529.1860
1/4	123.3078	1209.9577	1/4	139.0158	1537.8622
3/8	123.7005	1217.6768	3/8	139.4085	1546.5530
1/2	124.0932	1225.4203	1/2	139.8012	1555.2883
5/8	124.4859	1233.1884	5/8	140.1939	1564.0382
3/4	124.9787	1240.9810	3/4	140.5866	1572.8125
7/8	125.2713	1248.7982	7/8	140.9793	1581.6115
40 in.	125.6640	1256.6400	45 in.	141.3720	1590.4350
1/8	126.0567	1264.5062	1/8	141.7647	1599.2830
1/4	126.4494	1272.3970	1/4	142.1574	1608.1555
3/8	126.8421	1280.3124	3/8	142.5501	1617.0427
1/2	127.2348	1288.2523	1/2	142.9428	1625.9743
5/8	127.6275	1296.2168	5/8	143.3355	1634.9205
3/4	128.0202	1304.2057	3/4	143.7382	1643.8912
7/8	128.4129	1312.2193	7/8	144.1209	1652.8865
41 in.	128.8056	1320.2574	46 in.	144.5136	1661.9064
1/8	129.1983	1328.3200	1/8	144.9063	1670.9507
1/4	129.5910	1336.4071	1/4	145.2990	1680.0196
3/8	129.9837	1344.5189	3/8	145.6917	1689.1031
1/2	130.3764	1352.6551	1/2	146.0844	1698.2311
5/8	130.7691	1360.8159	5/8	146.4771	1707.3737
3/4	131.1618	1369.0012	3/4	146.8698	1716.5407
7/8	131.5545	1377.2111	7/8	147.2625	1725.7324
42 in.	131.9472	1385.4456	47 in.	147.6552	1734.9486
1/8	132.3399	1393.7045	1/8	148.0479	1744.1893
1/4	132.7326	1401.9880	1/4	148.4406	1753.4545
3/8	133.1253	1470.2961	3/8	148.8333	1762.7344
1/2	133.5180	1418.6287	1/2	149.2260	1772.0587
5/8	133.9107	1426.9859	5/8	149.6187	1781.3976
3/4	134.3034	1435.3675	3/4	150.0114	1790.7610
7/8	134.6961	1443.7738	7/8	150.4041	1800.1490

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
48 in.	150.7968	1809.5616	53 in.	166.5048	2206.1886
1/8	151.1895	1818.9986	1/8	166.8975	2216.6074
1/4	151.5822	1828.4602	1/4	167.2902	2227.0507
3/8	151.9749	1837.9364	3/8	167.6829	2237.5187
1/2	152.3676	1847.4571	1/2	168.0756	2248.0111
5/8	152.7603	1856.9924	5/8	168.4683	2258.5281
3/4	153.1530	1868.5521	3/4	168.8610	2269.0696
7/8	153.5457	1876.1365	7/8	169.2537	2279.6357
49 in.	153.9384	1885.7454	54 in.	169.6464	2290.2264
1/8	154.3311	1895.3788	1/8	170.0391	2300.8415
1/4	154.7238	1905.0367	1/4	170.4318	2311.4812
3/8	155.1165	1914.7093	3/8	170.8245	2322.1455
1/2	155.5092	1924.4263	1/2	171.2172	2332.8343
5/8	155.9019	1934.1579	5/8	171.6099	2343.5477
3/4	156.2946	1943.9140	3/4	172.0026	2354.2855
7/8	156.6873	1953.6947	7/8	172.3593	2365.0480
50 in.	157.0800	1963.5000	55 in.	172.7880	2375.8350
1/8	157.4727	1973.3297	1/8	173.1807	2386.6465
1/4	157.8654	1983.1840	1/4	173.5734	2397.4825
3/8	158.2581	1993.0529	3/8	173.9661	2408.3432
1/2	158.6508	2002.9663	1/2	174.3588	2419.2283
5/8	159.0435	2012.8943	5/8	174.7515	2430.1833
3/4	159.4362	2022.8467	3/4	175.1442	2441.0772
7/8	159.8289	2032.8238	7/8	175.5369	2452.0310
51 in.	160.2216	2042.8254	56 in.	175.9296	2463.0144
1/8	160.6143	2052.8515	1/8	176.3323	2474.0222
1/4	161.0070	2062.9021	1/4	176.7150	2485.3546
3/8	161.3997	2072.9764	3/8	177.1077	2496.1116
1/2	161.7924	2083.0771	1/2	177.5004	2507.1931
5/8	162.1851	2093.2014	5/8	177.8931	2518.2992
3/4	162.5778	2103.3502	3/4	178.2858	2529.4297
7/8	162.9705	2113.5236	7/8	178.6785	2543.5849
52 in.	163.3632	2123.7216	57 in.	179.0712	2551.7646
1/8	163.7559	2133.9440	1/8	179.4639	2562.9688
1/4	164.1486	2144.1910	1/4	179.8566	2574.1975
3/8	164.5413	2154.4626	3/8	180.2493	2585.4509
1/2	164.9340	2164.7587	1/2	180.6423	2596.7287
5/8	165.3267	2175.0794	5/8	181.0347	2608.0311
3/4	165.7194	2185.4245	3/4	181.4274	2619.3580
7/8	166.1121	2195.7943	7/8	181.8201	2630.7095

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
58 in.	182.2128	2642.0856	63 in.	197.9208	3117.2526
1/8	182.6055	2653.4861	1/8	198.3135	3129.6349
1/4	182.9982	2664.9112	1/4	198.7062	3142.0417
3/8	183.3909	2676.3609	3/8	199.0989	3154.4732
1/2	183.7836	2687.8351	1/2	199.4916	3166.9291
5/8	184.1763	2699.3338	5/8	199.8843	3179.4096
3/4	184.5690	2710.8571	3/4	200.2770	3191.9146
7/8	184.9617	2722.4050	7/8	200.6697	3204.4442
59 in.	185.3544	2733.9774	64 in.	201.0624	3216.9984
1/8	185.7471	2745.5743	1/8	201.4551	3229.5770
1/4	186.1398	2757.1957	1/4	201.8478	3242.1782
3/8	186.5325	2768.8418	3/8	202.2405	3254.8080
1/2	186.9252	2780.5123	1/2	202.6332	3267.4603
5/8	187.3179	2792.2074	5/8	203.0259	3280.1372
3/4	187.7106	2803.9270	3/4	203.4186	3292.8385
7/8	188.1033	2815.6712	7/8	203.8113	3305.5645
60 in.	188.4960	2827.4400	65 in.	204.2040	3318.3151
1/8	188.8887	2839.2332	1/8	204.5917	3331.0900
1/4	189.2814	2851.0510	1/4	204.9894	3343.8875
3/8	189.6741	2862.8934	3/8	205.3821	3356.7137
1/2	190.0668	2874.7603	1/2	205.7748	3369.5623
5/8	190.4595	2886.6517	5/8	206.1675	3382.4355
3/4	190.8522	2898.5677	3/4	206.5602	3395.3332
7/8	191.2419	2910.5083	7/8	206.9529	3408.2555
61 in.	191.6376	2922.4734	66 in.	207.3456	3421.2024
1/8	192.0303	2934.4630	1/8	207.7383	3434.1737
1/4	192.4230	2946.4771	1/4	208.1310	3447.1676
3/8	192.8157	2958.5159	3/8	208.5237	3468.1901
1/2	193.2084	2970.5791	1/2	208.9164	3473.2351
5/8	193.6011	2982.6669	5/8	209.3091	3486.3047
3/4	193.9931	2994.7792	3/4	209.7018	3499.3987
7/8	194.3865	3006.9161	7/8	210.0945	3512.5174
62 in.	194.7792	3019.0776	67 in.	210.4872	3525.6606
1/8	195.1719	3031.2635	1/8	210.8799	3538.8283
1/4	195.5646	3043.4740	1/4	211.2726	3552.0185
3/8	195.9573	3055.7091	3/8	211.6653	3565.2374
1/2	196.3500	3067.9687	1/2	212.0580	3578.4787
5/8	196.7427	3080.2529	5/8	212.4507	3591.7446
3/4	197.1354	3092.5615	3/4	212.8434	3605.0350
7/8	197.5281	3104.8948	7/8	213.2361	3618.3300

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
68 in.	213.6288	3631.6896	73 in.	229.3368	4185.3966
1/8	214.0215	3645.0536	1/8	229.7295	4199.7424
1/4	214.4142	3658.4402	1/4	230.1222	4214.1107
3/8	214.8069	3671.8554	3/8	230.5149	4228.5077
1/2	215.1996	3685.2931	1/2	230.9076	4242.9271
5/8	215.5923	3698.7554	5/8	231.3003	4257.3711
3/4	215.9850	3712.2421	3/4	231.6930	4271.8396
7/8	216.3777	3725.7535	7/8	232.0857	4286.3327
69 in.	216.7704	3739.2894	74 in.	232.4784	4300.8504
1/8	217.1631	3752.8498	1/8	232.8711	4315.3926
1/4	217.5558	3766.4327	1/4	233.2638	4329.9572
3/8	217.9485	3780.0443	3/8	233.6565	4344.5505
1/2	218.3412	3793.6783	1/2	234.0492	4359.1663
5/8	218.7339	3807.3369	5/8	234.4419	4373.8067
3/4	219.1266	3821.0200	3/4	234.8346	4388.4715
7/8	219.5193	3834.7277	7/8	235.2273	4403.1610
70 in.	219.9120	3848.4600	75 in.	235.6200	4417.8750
1/8	220.3047	3862.2167	1/8	236.0127	4432.6135
1/4	220.6974	3875.9960	1/4	236.4054	4447.3745
3/8	221.0901	3889.8039	3/8	236.7981	4462.1642
1/2	221.4828	3903.6343	1/2	237.1908	4476.9763
5/8	221.8755	3917.4893	5/8	237.5835	4491.8130
3/4	222.2682	3931.3687	3/4	237.9762	4506.6742
7/8	222.6609	3945.2728	7/8	238.3689	4521.5600
71 in.	223.0536	3959.2014	76 in.	238.7616	4536.4704
1/8	223.4463	3973.1545	1/8	239.1543	4551.4023
1/4	223.8390	3987.1301	1/4	239.5470	4566.3626
3/8	224.2317	4001.1344	3/8	239.9397	4581.3486
1/2	224.6244	4015.1611	1/2	240.3324	4596.3571
5/8	225.0171	4029.2124	5/8	240.7251	4611.3902
3/4	225.4098	4043.2882	3/4	241.1178	4626.4477
7/8	225.8025	4057.3886	7/8	241.5105	4641.5299
72 in.	226.1952	4071.5136	77 in.	241.9032	4656.6366
1/8	226.5879	4085.6631	1/8	242.2959	4671.7678
1/4	226.9806	4099.8350	1/4	242.6886	4686.9215
3/8	227.3733	4114.0356	3/8	243.0813	4702.1039
1/2	227.7660	4128.2587	1/2	243.4740	4717.3087
5/8	228.1587	4142.5064	5/8	243.8667	4732.5381
3/4	228.5514	4156.7785	3/4	244.2594	4747.7920
7/8	228.9441	4171.0753	7/8	244.6521	4763.0705

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
78 in.	245.0448	4778.3736	83 in.	260.7528	5410.6206
1/8	245.4375	4793.7012	1/8	261.1455	5426.9299
1/4	245.8302	4809.0512	1/4	261.5382	5443.2617
3/8	246.2229	4824.4299	3/8	261.9309	5459.6222
1/2	246.6156	4839.8311	1/2	262.3236	5476.0051
5/8	247.0083	4855.2568	5/8	262.7163	5492.4118
3/4	247.4010	4870.7071	3/4	263.1090	5508.8446
7/8	247.7937	4886.1820	7/8	263.5017	5525.3012
79 in.	248.1864	4901.6814	84 in.	263.8944	5541.7824
1/8	248.5791	4917.2053	1/8	264.2871	5558.2881
1/4	248.9718	4932.7517	1/4	264.6798	5574.8162
3/8	249.3645	4948.3268	3/8	265.0725	5591.3730
1/2	249.7572	4963.9243	1/2	265.4652	5607.9523
5/8	250.1499	4979.5456	5/8	265.8579	5624.5554
3/4	250.5426	4995.1930	3/4	266.2506	5641.1845
7/8	250.9353	5010.8642	7/8	266.6433	5657.8357
80 in.	251.3280	5026.5600	85 in.	267.0360	5674.5150
1/8	251.7207	5042.2803	1/8	267.4287	5691.2170
1/4	252.1134	5058.0230	1/4	267.8214	5707.9415
3/8	252.5061	5073.7944	3/8	268.2141	5724.6947
1/2	252.8988	5089.5883	1/2	268.6068	5741.4703
5/8	253.2915	5106.4060	5/8	268.9997	5758.2697
3/4	253.6842	5121.2497	3/4	269.3922	5775.0952
7/8	254.0769	5137.1173	7/8	269.7849	5791.9445
81 in.	254.4696	5153.0094	86 in.	270.1776	5808.8184
1/8	254.8623	5168.9260	1/8	270.5703	5825.7168
1/4	255.2550	5184.8651	1/4	270.9630	5842.6376
3/8	255.6477	5200.8329	3/8	271.3557	5859.5871
1/2	256.0404	5216.8231	1/2	271.7484	5876.5591
5/8	256.4331	5232.8371	5/8	272.1411	5893.5549
3/4	256.8258	5248.8772	3/4	272.5338	5910.5767
7/8	257.2105	5264.9411	7/8	272.9265	5927.6224
82 in.	257.6112	5281.0296	87 in.	273.3192	5944.6926
1/8	258.0039	5297.1426	1/8	273.7119	5961.7873
1/4	258.3966	5313.2780	1/4	274.1046	5978.9045
3/8	258.7893	5329.4421	3/8	274.4973	5996.0504
1/2	259.1820	5345.6287	1/2	274.8900	6013.2187
5/8	259.5747	5361.8391	5/8	275.2827	6030.4108
3/4	259.9674	5378.0755	3/4	275.6754	6047.6290
7/8	260.3601	5394.3358	7/8	276.0681	6064.8710

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
88 in.	276.4608	6082.1376	93 in.	292.1688	6792.9248
1/8	276.8535	6099.4287	1/8	292.5615	6811.1974
1/4	277.2462	6116.7422	1/4	292.9542	6829.4927
3/8	277.6389	6134.0844	3/8	293.3469	6847.8167
1/2	278.0316	6151.4491	1/2	293.7396	6866.1631
5/8	278.4243	6169.8376	5/8	294.1323	6884.5338
3/4	278.8170	6186.2591	3/4	294.5350	6902.9296
7/8	279.2097	6203.6905	7/8	294.9177	6921.3497
89 in.	279.6024	6221.1534	94 in.	295.3104	6939.7946
1/8	279.9951	6238.6408	1/8	295.7031	6958.2636
1/4	280.3878	6256.1507	1/4	296.0958	6976.7552
3/8	280.7805	6273.6893	3/8	296.4885	6995.2755
1/2	281.1732	6291.2503	1/2	296.8812	7013.8183
5/8	281.5659	6308.8351	5/8	297.2739	7032.3853
3/4	281.9586	6326.4460	3/4	297.6666	7050.9775
7/8	282.3513	6344.0807	7/8	298.0593	7069.5940
90 in.	282.7440	6361.7400	95 in.	298.4520	7088.2352
1/8	283.1367	6379.4238	1/8	298.8447	7106.9005
1/4	283.5294	6397.1300	1/4	299.2374	7125.5885
3/8	283.9221	6414.8649	3/8	299.6301	7144.3052
1/2	284.3148	6432.6223	1/2	300.0228	7163.0443
5/8	284.7075	6450.4039	5/8	300.4155	7181.8077
3/4	285.1002	6468.2107	3/4	300.8082	7200.5962
7/8	285.4929	6486.0418	7/8	301.2009	7219.4090
91 in.	285.8856	6503.8974	96 in.	301.5936	7238.2466
1/8	286.2783	6521.7772	1/8	301.9863	7257.1083
1/4	286.6710	6539.6801	1/4	302.3790	7275.9926
3/8	287.0637	6557.6114	3/8	302.7717	7294.9056
1/2	287.4564	6573.5651	1/2	303.1644	7313.8411
5/8	287.8491	6593.5431	5/8	303.5571	7332.8008
3/4	288.2418	6611.5462	3/4	303.9498	7351.7857
7/8	288.6345	6629.5736	7/8	304.3425	7370.7949
92 in.	289.0272	6647.6258	97 in.	304.7352	7389.8288
1/8	289.4199	6665.7021	1/8	305.1279	7408.8868
1/4	289.8125	6683.8010	1/4	305.5206	7427.9675
3/8	290.2053	6701.9286	3/8	305.9133	7447.0769
1/2	290.5980	6720.0787	1/2	306.3060	7466.2087
5/8	290.9907	6738.2530	5/8	306.6987	7485.3648
3/4	291.3834	6756.4525	3/4	307.0914	7504.5460
7/8	291.7661	6774.6763	7/8	307.4841	7523.7515

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
98 in.	307.8768	7542.9818	$\frac{1}{8}$	311.4111	7717.1563
$\frac{1}{8}$	308.2695	7562.2362	$\frac{1}{4}$	311.8038	7736.6297
$\frac{1}{4}$	308.6622	7581.5132	$\frac{3}{8}$	312.1965	7756.1318
$\frac{3}{8}$	309.0549	7600.8189	$\frac{1}{2}$	312.5892	7775.6563
$\frac{1}{2}$	309.4476	7620.1471	$\frac{5}{8}$	312.9819	7795.2051
$\frac{5}{8}$	309.8403	7639.4995	$\frac{3}{4}$	313.3746	7814.7790
$\frac{3}{4}$	310.2330	7658.8771	$\frac{7}{8}$	313.7673	7834.3772
$\frac{7}{8}$	310.6257	7678.2790			
			100 in.	314.1600	7854.0000
99 in.	311.0184	7697.7056			

A TABLE

Showing the Pressure of Steam from 2½lbs up to 60lbs; and the height of a Column of Mercury, and the number of Feet and Inches of Water in a Column at the different Pressures.

Pressure of Steam.	Inches of Mercury Column.	Feet and Inches of Water in height at the Temperature and Pressure.	
Pounds.	Inches.	Feet.	Inches.
2½	5·15	5	9
3	6·18	6	11
3½	7·21	8	0¾
4	8·24	9	2¼
4½	9·27	10	4
5	10·30	11	6
5½	11·33	12	8
6	12·36	13	10
6½	13·39	15	0
7	14·42	16	2
7½	15·45	17	4½
8	16·48	18	5
10	20·60	23	0½
12	24·72	27	8
15	39·90	34	6
20	41·20	46	1¼
25	51·50	57	7½
30	61·80	69	1½
35	72·12	86	8
40	82·41	92	2½
45	92·70	103	9
50	103·00	115	3
55	113·31	126	9
60	123·60	138	3½
Additional Column of 2·037 Inches of Mercury for each extra pound pressure.		2 feet 3½ inches of a column extra for each increased pound pressure.	

Steam produced from impure water is not of equal density to steam from pure water. Steam from pure water at a temperature of 212 degrees, supports a column of mercury 30 inches; and steam from sea water at the same temperature supports only 22¾ inches. Common water, at a temperature of 220 degrees, supports 35 inches; and sea water, at the same temperature, 26½ inches of a column of mercury. Pressure and temperature in this case varies. In all cases where accuracy of pressure is requisite, an open column of mercury is the most sensitive and correct indicator.

A TABLE

Showing the Temperature of Steam at different Pressures, from 1lb per Square Inch to 240lbs, and the quantity of Steam produced from a Cubic Inch of Water, according to Pressure.

NOTE.—Add the pressure of the atmosphere, 15lbs, to the pressure on the steam gauge, to correspond with the table.

Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.	Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.
1	102·9	20868	32	255·5	833
2	126·1	10874	33	257·3	810
3	141·0	7437	34	259·1	788
4	152·3	5685	35	260·9	767
5	161·4	4617	36	262·6	748
6	169·2	3897	37	264·3	729
7	175·9	3376	38	265·9	712
8	182·0	2983	39	267.5	695
9	187·4	2674	40	269·1	679
10	192·4	2426	41	270·6	664
11	197·0	2221	42	272·1	649
12	201·3	2050	43	273·6	635
13	205·3	1904	44	275·0	622
14	209·1	1778	45	276·4	610
15 Press. of Atmsphr.	212·8	1669	46	277·8	598
16	216·3	1573	47	279·2	586
17	219·6	1488	48	280·5	575
18	222·7	1411	49	281·9	564
19	225·6	1343	50	283·2	554
20	228·5	1281	51	284·4	544
21	231·2	1225	52	285·7	534
22	233·8	1174	53	286·9	525
23	236·3	1127	54	288·1	516
24	238·7	1084	55	289·3	508
25	241·0	1044	56	290·5	500
26	243·3	1007	57	291·7	492
27	245·5	973	58	292·9	484
28	247·6	941	59	294·2	477
29	249·6	911	60	295·6	470
30	251·6	883	61	296·9	463
31	253·6	857	62	298·1	456

Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.	Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.
63	299·2	449	89	323·5	328
64	300·3	443	90	324·3	325
65	301·3	437	91	325·1	322
66	302·4	431	92	325·9	319
67	303·4	425	93	326·7	316
68	304·4	419	94	327·5	313
69	305·4	414	95	328·2	310
70	306·4	408	96	329·0	307
71	307·4	403	97	329·8	304
72	308·4	398	98	330·5	301
73	309·3	393	99	331·3	298
74	310·3	388	100	332·0	295
75	311·2	383	110	339·2	271
76	312·2	379	120	345·8	251
77	313·1	374	130	352·1	233
78	314·0	370	140	357·9	218
79	314·9	366	150	363·4	205
80	315·8	362	160	368·7	193
81	316·7	358	170	373·6	183
82	317·6	354	180	378·4	174
83	318·4	350	190	382·9	166
84	319·3	346	200	387·3	158
85	320·1	342	210	391·5	151
86	321·0	339	220	395·5	145
87	321·8	335	230	399·4	140
88	322·6	332	240	403·1	134

This table shows that the saving of fuel is in proportion to the increase of pressure. The advantage of generating and using high-pressure steam is thereby made apparent. The table shows that the last 10lbs of additional pressure only requires four degrees of heat to raise it; whereas the first 10lbs of pressure above the atmosphere requires 29 additional degrees of heat to raise it—a difference of 25 degrees. Hence a small accession of heat at a high temperature produces an increase of elastic force; and a small abstraction of heat reduces its bulk, by the application of cold, in the ratio of its density; proving the advantage of clothing cylinders, steam-pipes, boilers, &c., with a non-conductor of heat or cold —a sure saving of fuel, where adopted, and more particularly required where high-pressure steam is used.

A TABLE

SHOWING THE WEIGHT OF WATER IN PIPES OF VARIOUS DIAMETERS, ONE FOOT IN LENGTH.

Diameter in Inches.	Weight in Pounds.	Diameter in Inches.	Weight in Pounds.	Diameter in Inches.	Weight in Pounds.
3	3	12¼	51	23	180¼
3¼	3½	12½	53¼	23½	188¼
3½	4¼	12¾	55½	24	196¼
3¾	4¾	13	57½	24½	204½
4	5½	13¼	59¾	25	213
4¼	6¼	13½	62¼	25½	221½
4½	7	13¾	64½	26	230½
4¾	7¾	14	66¾	26½	239½
5	8½	14¼	69¼	27	248½
5¼	9¼	14½	71½	27½	257¾
5½	10¼	14¾	74¼	28	267¼
5¾	11¼	15	76¾	28½	276¾
6	12¼	15¼	79¼	29	286½
6¼	13¼	15½	82	29½	296½
6½	14½	15¾	84½	30	306¾
6¾	15½	16	87¼	30½	317¼
7	16¾	16¼	90	31	327½
7¼	18	16½	92¼	31½	338¼
7½	19¼	16¾	95½	32	349
7¾	20½	17	98½	32½	360
8	21¾	17¼	101½	33	371¼
8¼	23¼	17½	104½	33½	382½
8½	24½	17¾	107½	34	394
8¾	26	18	110½	34½	405¾
9	27½	18¼	113½	35	417½
9¼	29¼	18½	116½	35½	429½
9½	30¾	18¾	119¾	36	441¾
9¾	32½	19	123	36½	454
10	34	19¼	126¼	37	466½
10¼	35½	19½	129½	37½	479¼
10½	37½	19¾	132	38	492¼
10¾	39¼	20	136¼	38½	505¼
11	41¼	20½	143¼	39	518½
11¼	43¼	21	150¼	39½	531¾
11½	45	21½	157½	40	545½
11¾	47	22	165		
12	49	22½	172½		

DURABLE CEMENT FOR STEAM AND WATER JOINTS, GAS RETORTS, &c.

Take 10lbs of Ground Litharge, 4lbs of Ground Paris White, ½lb of Yellow Ochre, 2lbs of Red Lead, ½oz. of Hemp, cut into lengths of half-an-inch. Mix all together with Boiled Linseed Oil, to the consistence of very stiff Putty. Make the joint with the Cement in the usual way. The above mixture well made, will set quickly when heat is applied. It answers well for the joints of steam pipes, for leakages in Boilers, for cisterns, gas retorts, or any other purpose requiring a durable Cement. It resists fire, and will set in water.

See that the whole is well ground and mixed together.

Be particular that the Litharge is good. It is too often adulterated by the retail dealers.

Since this receipt was first published, several parties make and vend the Cement, but of a very inferior quality—the greatest portion of the ingredients being Bristol Brick and Sea Sand, with a little Litharge.

The Cement may be had, mixed, of Messrs. HOPKINSON AND Co., Britannia Works, Huddersfield, in Casks at 42/- per Cwt.

USEFUL CEMENT FOR RESERVOIRS, CISTERNS, WALLS, WATER COURSES, &c.

Take 90 parts of well-burnt Brick or Clay (Fire Brick is the best) and 10 parts of Litharge, well pulverised and mixed together with Boiled Linseed Oil, to the consistency of thin plaster.

Use it in the same manner as plaster, previously wetting the parts to be covered with water. This last precaution is indispensable, or the Oil will be absorbed, and prevent the Cement from hardening. Applied in the mode stated, in three or four days the Cement will become firm.

B. BROWN, PRINTER, HUDDERSFIELD.

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BY JOSEPH HOPKINSON.

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